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UNIVERSITY OF TORONTO
DEPARTMENT OF UNIVERSITY EXTENSION

EVENING LECTURES ON GEOLOGY

by

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ERRATA

Page 1 - 6 lines from bottom - for groups read group.
" 4 - line 5 - for rock read melt.
" 7 - centre of page - for In the above table the deep seated rocks read The deep seated rocks of the above table.
" 9 - line 1 - for any rain storm read a heavy rain storm.
" 9 - 9 lines from bottom - for washed read wash.
" 13 - 4 lines from bottom - for trought read trough.
" 16 - line 3 - after gentle add in directions.
" 20 - line 9 - after which add feature .
" 20 - line 10 - first word - for increase read decrease.
" 23 - 3 lines from bottom - after is add a.
" 26 - paragraph 5 - line 5 - after to add the.
" 28 - paragraph 5 - line 5 - after to add a.
" 29 - 13 lines from bottom - after mass add of granite.
" 30 - paragraph 3 - line 8 - after centre add or toward the base.
" 30 - 3 lines from bottom - for boey read body.
" 32 - 3 lines from bottom - after pressures, for rocks read a rock.
" 34 - line 17 - for makes read masks.
" 35 - line 31 - for destroys read may destroy.
" 35 - line 38 - after gregate add a.
" 38 - line 16 - for so read as.
" 44 - 15 lines from bottom - for finite read flints.
" 44 - line 3 from bottom - after to for those read these are.
" 53 - line 16 - after rock. add In addition we should note that.
" 53 - line 18 - for line read lime.
" 57 - 3 lines from bottom - for of Antimony read or Antimony.
" 63 - line 11 - for north read west.
" 75 - 6 lines from bottom - for Ordivician read Ordovician.
" 75 - 2 lines from bottom - " " " "
" 77 - 8 lines from bottom - for invertebrates read vertebrates.
" 81 - 15 lines from bottom - for basis read basins.
" 82 - line 18 - for modification read modifications.
" 85 - line 17 - after age add in North America.
" 86 - line 1 - after the add Mesozoic and.
" 90 - 2 lines from bottom - for systems of Canada. read systems of Northern North America.
" 91 - line 2 - for with read and.
" 100 - line 1 - for us read is.

UNIVERSITY OF TORONTO
DEPARTMENT OF UNIVERSITY EXTENSION

The earth is made of a number of elements - some 92 in all. These include nitrogen, oxygen, silicon, aluminium, calcium, sodium, potassium, magnesium, iron, copper, lead, and many others to make up the total.

With all of these elements present in the earth it is interesting to note that much the greater part of the earth's crust is made up of a relatively small number - eight in all. These are:

Aluminium (Al)	Silicon (Si)	Oxygen (O)
Potassium (K)		
Sodium (Na)		
Calcium (Ca) (Lime)		
Magnesium (Mg)		
Iron (Fe)		

and these, combining with each other, make up about 98% of the earth's crust. The other 2% must be allotted to all of the other 84 elements.

For the sake of easy reference, a shorthand symbol is adopted for each of the elements, and in the table above these symbols are placed to the right of the names of the elements.

It rarely happens in nature that the elements occur free and uncombined. Oxygen combines readily with all of them, and since it has been easily available in past times, all the above elements have long since combined with it to form aluminum oxygen, sodium oxygen, silicon oxygen compounds, etc. These are called the oxides of aluminum, potassium, etc., and for convenience these compounds are indicated by a union of the symbols as:

Al_2O_3	SiO_2
K_2O	
Na_2O	
CaO	
MgO	
FeO	

Some of these oxides occur in nature as simple oxides, but usually the oxides of the left hand group unite with the oxide of silicon to form a more complex substance. For convenience we will designate the oxide of silicon as an acid oxide and the oxides of the other groups as basic oxides. An example of this union is given, as when 1 aluminium oxide with 1 potassium oxide groups together to unite with 6 silicon oxides. This is sometimes written $Al_2O_3.K_2O.6SiO_2$, and is called the aluminium potassium silicate. This silicate is a hard mineral called orthoclase.

From these combinations of the oxides of the left hand group (basic) with the oxide of silicon (acid), we get the above and a number of others as:

$Al_2O_3K_2O6SiO_2$ - orthoclase (Or)
$Al_2O_3Na_2O6SiO_2$ - albite (Ab)
$Al_2O_3CaO2SnO_2$ - anorthite. (An)

If the two latter occur together they are apt to mingle so intimately - in any proportion - that they cannot readily be distinguished, and another name is given to the combination - plagioclase.

The orthoclase and plagioclases together are grouped as felspars and make up a great deal of the rocks in the earth's crust.

The oxides of iron and magnesium, together with those of calcium and aluminium also unite with silicon oxide to form another group of silicates. On account of the common presence of iron and magnesium these are sometimes called the ferromagnesian group. Usually these are heavy and dark in colour. The three more common members of this group are pyroxene, hornblende and biotite - the latter a mica.

After all the oxides of the left hand column have united with as much silica (silicon oxide) as they can use, it sometimes happens that there remains still more silica. This forms of itself a hard substance to which is given the name quartz - varying from glassy clear to milky to smoky in colour.

From the original oxides we now have:

Quartz - the silicon oxide - SiO_2

Orthoclase - the potash felspar ($Al_2O_3K_2O6SiO_2$)

Plagioclase (Pl) (Albite - the soda felspar ($Al_2O_3K_2O6SiO_2$)
(Anorthite - the lime felspar ($Al_2O_3CaO2SiO_2$)

Biotite)
Hornblende) - the ferromagnesian silicates.
Pyroxene)

The biotite, hornblende and pyroxene will be abbreviated as:

Biotite - Bi
Hornblende - Hb
Pyroxene - Py

Each of the compounds above listed tends to organize itself into a solid with a very definite plan of structure from which it rarely departs. This is called a crystal and the crystal structure is characteristic for each of the compounds. Characteristic also are such properties as colour, hardness, etc. Furthermore, all of these compounds so formed within the earth of definite composition and usually with characteristic crystal structure are called minerals. Since the minerals listed above are among those from which most of the rocks are made, they are often called the Rock Forming Minerals:

Quartz, orthoclase, plagioclase
biotite, hornblende and pyroxene.

ROCKS

The rocks of the earth are divisible into three main groups - the Igneous, the Sedimentary, and the Metamorphic.

The first group, the Igneous, includes those rocks which have solidified from molten solutions, e.g. granite, syenite, diorite, gabbro.

The second group, the Sedimentary, is the group of rocks which have been laid down under water, and later solidified, conglomerate, sandstone, shale, and limestone.

The third group, the Metamorphic, is made up of rocks which were originally either Igneous or Sedimentary, but since their origins have been so modified by the vicissitudes of heat and pressure within the earth's crust that they no longer resemble their former state, and are now called Metamorphic rocks.

The Igneous Rocks

The common oxides of the earth's crust have already been noted as:

Al_2O_3 SiO_2
K_2O
Na_2O
CaO
MgO
FeO

Let us suppose that deep in the earth there is a melt or solution of these oxides at very high temperatures, and that in this melt there is a very high proportion of: alumina (Al_2O_3)
potash (K_2O)
and silica (SiO_2) in abundance,

with smaller amounts of magnesium oxide (MgO)
and iron oxide (FeO).

As the solution begins to cool the oxides will tend to combine to make various minerals.

The alumina (Al_2O_3), potash (K_2O), and silica (SiO_2) will almost surely group to form the potash felspar - $Al_2O_3.K_2O.6SiO_2$ (orthoclase).

The iron, magnesia and silica will group to form the ferromagnesian silicate, hornblende, or, perchance, biotite.

Since there was silica in abundance, there will still be some of this left over, and it will form of itself quartz, (SiO_2).

We thus have three compounds beginning to segregate in the solution:

Silica (Quartz)
Potash felspar (Orthoclase) and a
Ferro magnesian silicate (Hornblende),(or Biotite)

As the rock further cools, each of these compounds will organize itself into a number of crystals, growing throughout the whole mass, and finally, when cooled, the mass will be made up of an enormous number of crystals of:

Quartz (Qtz)
Orthoclase (Or)
Biotite or Hornblende (Hb), or (Bi)

A rock of this composition is called a granite:

Qtz)
Or) - Granite
Bi or Hb)

In another case the melt may have all the oxides as above, but, with just sufficient silica to make the felspar and the ferromagnesian crystals, and with none left over to form quartz. Hence the rock, when cooled, would show no crystals of quartz, but only those of orthoclase (Or) and hornblende (Hb) or biotite (Bi). This rock is called a syenite.

Or)
Bi or Hb) - Syenite

This rock, it is noticed, is just like a granite with the quartz left out.

Let us now assume another melt, or solution, also deep in the earth, but in this case let there be little or no potassium oxide while there is an abundance of sodium and calcium oxides. with a smaller amount of iron oxide and magnesium oxide, and just enough silica (SiO_2) to combine with these other oxides.

Al_2O_3 SiO_2
Na_2O
CaO
MgO
FeO

As the melt cools and the oxides begin to combine with each other, we have the alumina (Al_2O_3), soda (Na_2O), lime (CaO), and silica (SiO_2) arranging themselves as follows:

$Al_2O_3Na_2O6SiO_2$ (albite) and $Al_2O_3CaO2SiO_2$ (anorthite) Plagioclase (soda lime felspar) (5)

These groupings, it will be recalled, are known as albite and anorthite, which, when they are together, mingle so intimately with each other that they appear, when solidified, as one crystal - plagioclase - the soda lime felspar.

The ferromagnesian oxides will, in this case, also combine with the silica to form hornblende, and, as the melt solidifies, two sets of crystals begin to grow, and when, after long ages, it is all cooled, we have a rock composed of a mixture of crystals of plagioclase and hornblende, in approximately equal amounts. This rock is called a diorite -

Pl)
Hb) Diorite

From these three examples we see that, depending upon the kind and amount of the different oxides in the melt, we have arrived at three different kinds of rocks, with different mineral composition:

Qtz)
Or) - Granite
Bi or Hb)

Or)
Bi or Hb) - Syenite

Pl)
Hb) - Diorite

Let us now imagine one more melt or solution with the same kind of oxides as in the diorite (silica, soda, lime, and ferromagnesian oxides), but let us suppose that the soda and lime oxides are present in much smaller amounts than in the diorite melt and the ferromagnesian in larger amounts, with just enough silica (SiO_2) to satisfy all the other oxides.

On cooling, the soda lime and silica will combine as before to make plagioclase, but in smaller proportion to the whole than in the diorite.

Commonly, when there is a small proportion of felspar and a large proportion of ferromagnesian mineral in the melt, the latter comes out, not as a hornblende, but as a pyroxene. This is the case we have here presumed, so that the rock, on crystallizing, will be seen to be made up of crystals of plagioclase and pyroxene. This rock is called a gabbro -

Pl)
Py) - Gabbro

Since in this rock - gabbro - there is a higher proportion of the ferromagnesian minerals, it will be heavier and darker in colour than the diorite.

Summarizing these groupings of minerals to form the rocks, we have:

Qtz)
Or) - Granite
Bi or Hb)

Or)
Bi or Hb) - Syenite

Pl)
Hb) - Diorite

Pl)
Py) - Gabbro

If we examine the mineral composition of these rocks we will notice that in the granite there is a higher proportion of the silica than in any of the other rocks, and that this proportion of silica to the other oxides decreases through the above series until it is at the lowest in the gabbro.

Since the silica is the acid representative of the oxides, it is therefore apparent that the granite is the most acid rock, and the gabbro the least acid or the more basic.

Moreover, since the basic minerals are darker and heavier than the acid, it follows that the rocks toward the basic end of the series will be darker and heavier than those at the acid end.

In all of these cases the rocks have been presumed to have formed at great depth and to have cooled slowly enough to allow the crystals to for leisurely and to grow without disturbance till they impinge on one another. This arrangement of crystals gives a texture characteristic of rocks which have cooled and frozen at great depth (deep seated rocks). This texture is called the granitoid texture.

In some cases, however, the melts may work up to the surface as hot liquids and be poured out on the surface as lavas. In these cases the crystals do not have time to grow fully and will be much smaller and with a more disturbed arrangement than in the deep seated rock. Although the mineral composition of a given lava may be the same as its corresponding deep seated parent, yet, since the appearance is so different from its parent, it is given a different name.

The names of the lavas corresponding to the different deep seated rocks already discussed is given below: (7)

Mineral Composition	Deep Seated rocks	Surface flow Lavas
Qtz) Or) Bi or Hb)	Granite	Rhyolite
Or) Bi or Hb)	Syenite	Trachyte
Pl) Hb)	Diorite	Andesite
Pl) Py)	Gabbro	Basalt.

In the above table the deep seated rocks have been very slow in cooling and are coarse grained, while the surface rocks have cooled rapidly and are fine grained. In some cases, however, the molten rock has migrated from its deep seated home toward the surface and has been forced into higher and narrower channels where it has cooled more slowly than the lavas but much more rapidly than the deep seated rocks. The rocks so formed in these narrower and higher channels are known as the intermediate rocks. In these rocks some of the crystals may be large and well formed, but are surrounded or imbedded in a mass of smaller crystals which in some cases are quite as small as the crystals of the surface flow. This texture - of larger crystals imbedded in the mass of smaller crystals - is called the porphyritic texture. This texture is common to many of the intermediate rocks, but is not an essential characteristic of them.

In the following table will be shown the names given to the intermediate rocks corresponding to the deep seated rocks, granite, syenite, diorite, and gabbro.

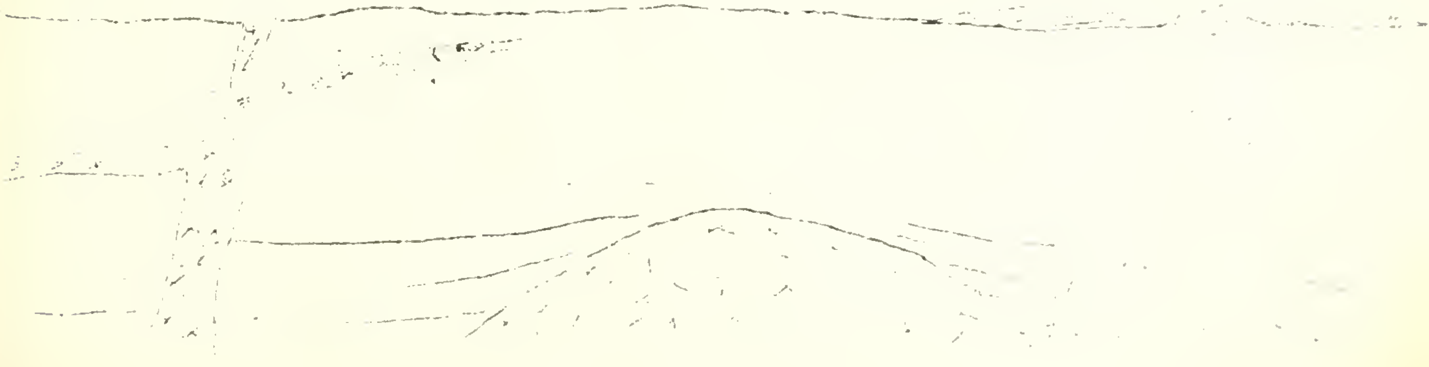
Table Showing Deep-Seated, Intermediate and Surface Igneous Rocks

Mineral Composition	Deep Seated	Intermediate	Surface Flow Lavas
Qtz) Or) Bi or Hb)	Granite	Qtz Porphyry Granite Porphyry	Rhyolite
Or) Bi or Hb)	Syenite	Porphyry Syenite Porphyry	Trachyte
Pl) Bi or Hb)	Diorite	Porphyrite	Andesite
Pl) Py)	Gabbro	Diabase	Basalt

This table gives a fair outline of the principal igneous rocks. There are a number of modifications of these rocks, most of which may be looked up as required, but there is one, the name of which frequently occurs in mining literature - granodiorite - and it will be briefly described. Granodiorite, as its name would imply, partakes of the character of a granite and a diorite having all the minerals of each:

Qtz)
Or)
Pl)
Hb) Granodiorite

In appearance the granodiorite may look much like the granite, but on closer inspection of the hand specimen, or with the microscope, the presence of sufficient plagioclase may be detected, along with the orthoclase to render it a granodiorite.



WEATHERING

After any rain storm it may be noted that the water trickling off the surface of the ground and then gathering into larger rivulets, is discolored with particles of mud which it is carrying in suspension. A closer examination will show also that it is rolling along the ground a large number of sand particles and small rock particles which are too heavy to be held up in the stream. All of these particles are on the way to larger streams, and from there to the rivers which ultimately will carry them to the lake or to the sea. These particles which are being hurried along by the running water have been washed off the soil and exposed rock from which they have been loosened by the action of weathering agents.

It is probable that at one time all of the earth's surface was made up of the different rocks previously described. They may have poured out on the surface as lavas in the first place, or they may have solidified deep in the earth and later, by slow earth forces, been brought ultimately to the top. Wherever these rocks were exposed to the atmosphere and to the changing temperature of day and night, they were slowly broken down - disintegrated and decomposed. The firmly bound grains of Quartz, Felspars, Hornblende or Pyroxene were loosened from one another by alternate expansions and contractions due to changes of temperature and gradually fell apart into an incoherent mass of individual grains. These grains were then attacked on all sides by the water, oxygen and carbon dioxide of the atmosphere. By these agents they were partly or wholly dissolved or decomposed.

The Felspars were decomposed to form clay (Kaolin) (insoluble) and some soluble carbonates such as Potassium Carbonate, Sodium Carbonate and Calcium Carbonate.

The Ferromagnesians were decomposed to form soluble carbonates of Magnesium, Calcium, and Iron, with some small amounts of the clay (Kaolin) (insoluble).

The Quartz is very resistant to these attacks and remains practically untouched by the attack of the atmosphere.

The soluble material is carried away by the trickling water - along the surface, in rivers or underground in springs, and then in rivers until finally it reaches the sea.

The insoluble substances - the Quartz and Kaolin - are left in the place where they were weathered till heavier rainfalls washed them into the streams where, as sand and mud, they also are swept out, ultimately to the sea. Along with this sand and mud, in the larger and stronger streams, are also larger rock fragments, such as pebbles, small boulders and gravel which, along with them, are rolled along toward the ocean.

Hence, the rock which originally was born deep within the earth and later, by various movements, was brought up to the earth's surface, has now been broken up by weathering and, in the disintegrated and decomposed form, has been borne by the rivers to the sea.

In the meantime, the rocks at the sea coast have been attacked by the waves of the ocean and the shore cliffs have been undermined and beaten down by the plunging waters at their base. The fragments from the rock cliffs may be broken to all degrees of fineness, so that ultimately the rock of the sea coast is ground by the waves to the form of gravel, sand and mud.

Thus, from the rivers that pour into the sea, and from the shore cliff at its margin, there is delivered to the waters of the ocean a load of gravel, sand and mud with much other material carried along in solution. The solid particles - gravel, sand and mud - are worked over by the advancing waves and carried seaward by the water retreating. The heavier and coarser material cannot be carried far, and hence the gravel is left as a long band just at or near the water level. The sand is carried farther out and the mud still farther than the sand before it is dropped from the quieter waters of the deeper sea. Thus, from the shore line outward, we have successive bands of, first gravel, then sand, and then mud, each gradually becoming thicker as the centuries go by, and the land is worn down and the debris carried out to the ocean.

In addition to the fragmental material that has been rolled along the bottom or carried in suspension in the streams, it was noted that a great part of the minerals had been decomposed to form new substances, some of which are soluble. Among these is Calcium Carbonate (Lime). This was carried out in solution and, being in solution, could be transported wherever the water travelled. It was not long in the ocean water, however, until small animals took some of this lime from solution and built it into their shells. In time the animals died and their shells were bequeathed to the ocean bottom as lime. This lime, together with other lime, precipitated from the water in different ways, gradually accumulated until there was built up a thickness of limey material almost as great as the mud and sand. Usually the accumulation of lime is a little farther out in the ocean than the muddy deposits already described.

Through many ages these accumulations of gravel, sand, mud, and lime are being built up with the bottom layers being more and more compressed as more load is added above them. Under the influence of this load and other factors the incoherent gravels, sands, muds, and limey oozes gradually become compressed to solid rocks, known respectively as conglomerate, sandstone, shale, and limestone.

Gravel - becomes Conglomerate

Sand - " Sandstone

Mud - " Shale

Limey ooze - " Limestone

Except for the presence of mud and other impurities the limestone is made up of Calcium Carbonate, a compound which represents the union of Calcium Oxide(CaO) and Carbon Dioxide(CO_2), usually written $CaCO_3$.

With this Calcium Carbonate there sometimes occur varying amounts of the Magnesium Carbonate ($MgCO_3$). When the amount of Magnesium Carbonate is about equal to the Calcium Carbonate, the rock is called a Dolomite.

FOLDING AND FAULTING

The sedimentary rocks which we have just considered were for the most part laid down in fairly level beds along the margins of the continents or in such interior seas as Hudson Bay is now. In the course of time the sediments so laid down were compressed and the individual grains cemented together to form the solid rocks - conglomerate, sandstone, shale and limestone, or dolomite.

The increasing thickness of all this mass of sandstone, shale, and limestone must ultimately make a tremendous load on the sea floor beneath it. This load tends to push this part of the sea floor down farther into the earth's crust wherever the sediments have been accumulating. To get into a lower place in the crust they must take up a position where the circumference is smaller and hence must have some difficulty in crowding down into the smaller space. The crowding develops a lateral thrust in the rocks at their margins and also in the sinking sediments themselves. This thrust in itself can be very great but there is in addition a fairly constant tangential thrust over the earth's crust during certain intervals of time. The latter thrust may be due to the shrinkage of the interior and an endeavour of the whole exterior crust to sink to a lower level and hence, of necessity, to shrink to a smaller shell at this lower level. Whatever may be the cause, there is developed in the crust this larger and major thrust tangential to the earth's surface. In those places where the sinking sediments are of themselves creating a thrust, and crowding themselves and their adjacent rocks to the disturbance of the whole area, the more widespread thrust finds a place to more easily express itself, and hence all the adjustment necessary for a wide area of the earth's crust is likely to be manifested in these bands where the sediments have been laid down. These bands are usually at the edges of the continents and the direction of the greatest thrust is usually at right angles to the margin of the continent. The thrust in its application is usually slow, but it is persistent and it is relentless, and the rocks must, in some way, adjust themselves to this enormous lateral pressure. Let us consider the manner in which this is done.

Some of the softer rocks may just thicken under the pressure just as a slab of putty or plasticene would thicken under pressure applied slowly from the sides. If in the case of the plasticene we were, however, to make up a composite slab of alternating layers of plasticene, paper and very thin sheets of lead or aluminium and then apply pressure to the sides, we would find that, instead of thickening, the slab would tend to buckle and bend rather than to thicken. If the width and length of the slab were very great compared to the thickness, we would find that it would develop a great many folds or buckles - upward and downward foldings alternating with each other. We could still identify the different layers of plasticene, paper and aluminium or lead, but they would no longer be in parallel planes but in parallel folds of the various materials.

In the same way the layers of the earth's crust which had been laid down in practically horizontal parallel layers may respond to the thrusts that are directed against their sides and transmitted through them. Very very slowly they begin to buckle into a number of folds, the

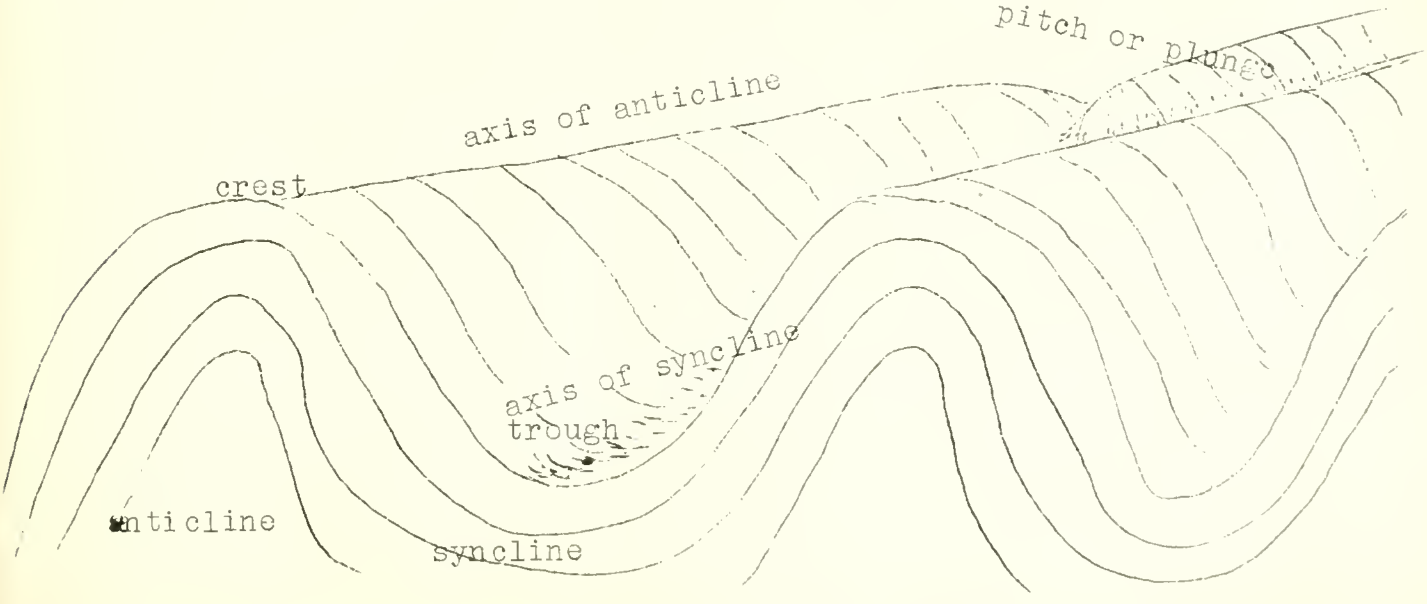
upthrusting parts of the folds alternating with the downthrusting parts of the folds and each of the folds developing more and more as the pressure or thrust is continued. After many many ages the thrust may exhaust itself and the beds will no longer feel the great pressure that had been crowding them for so long. But, the effects will remain in the long series of folds into which the rock has been bent. In many cases these bent and folded rocks have later been brought to the surface and we can now see the manner in which they have been bent and folded when deep within the earth.

Sometimes when the thrust has not been too severe or applied over a very great time, the folds have taken the form of gentle undulations: sometimes with a greater thrust the folds may have steeper sides and more sharply rounded tops and bottoms; and sometimes the thrust may have been so severe that the sides are pushed so close together that the beds on one side of the fold are practically parallel with the beds on the other side of the fold.

For the sake of convenience in speaking of folds or parts of folds a number of common names have been applied to the different kinds of folds and to the different parts of any of these folds.

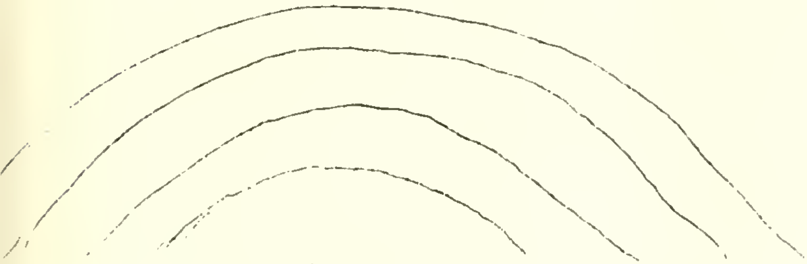
The upward pointing part of a fold is called an ANTICLINE.
The downward pointing part of a fold is called a SYNCLINE.
The top of the anticline is called the CREST of the ANTICLINE.
The bottom of the syncline is called the TROUGH of the SYNCLINE.
The side of an anticline is called the FLANK or LIMB of the anticline and it is to be noted that this is also the FLANK or LIMB of the adjacent syncline.

The line joining the crests of the succeeding beds in an anticline is called the AXIS of the anticline and the same term is also applied to the line running along the crest of the anticline. The AXIS of the syncline in the same way is the line running along the trough of the syncline or the line running down through the bottoms of the succeeding beds of the syncline.

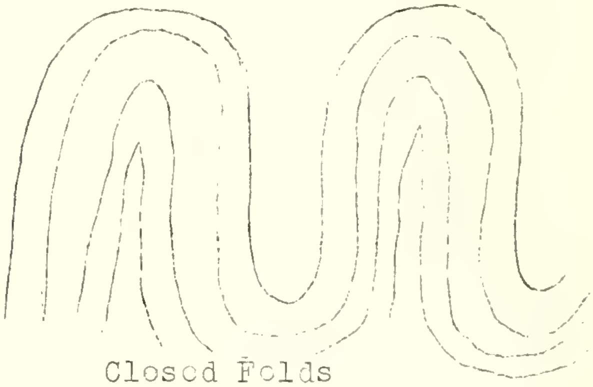


When the undulations are broad and the flanks of the anticline drop gently away from its crest the anticline is said to be an open anticline.

When the thrust has been severe and the beds on one side of the axis are almost parallel with the beds on the other side it is called a closed anticline.

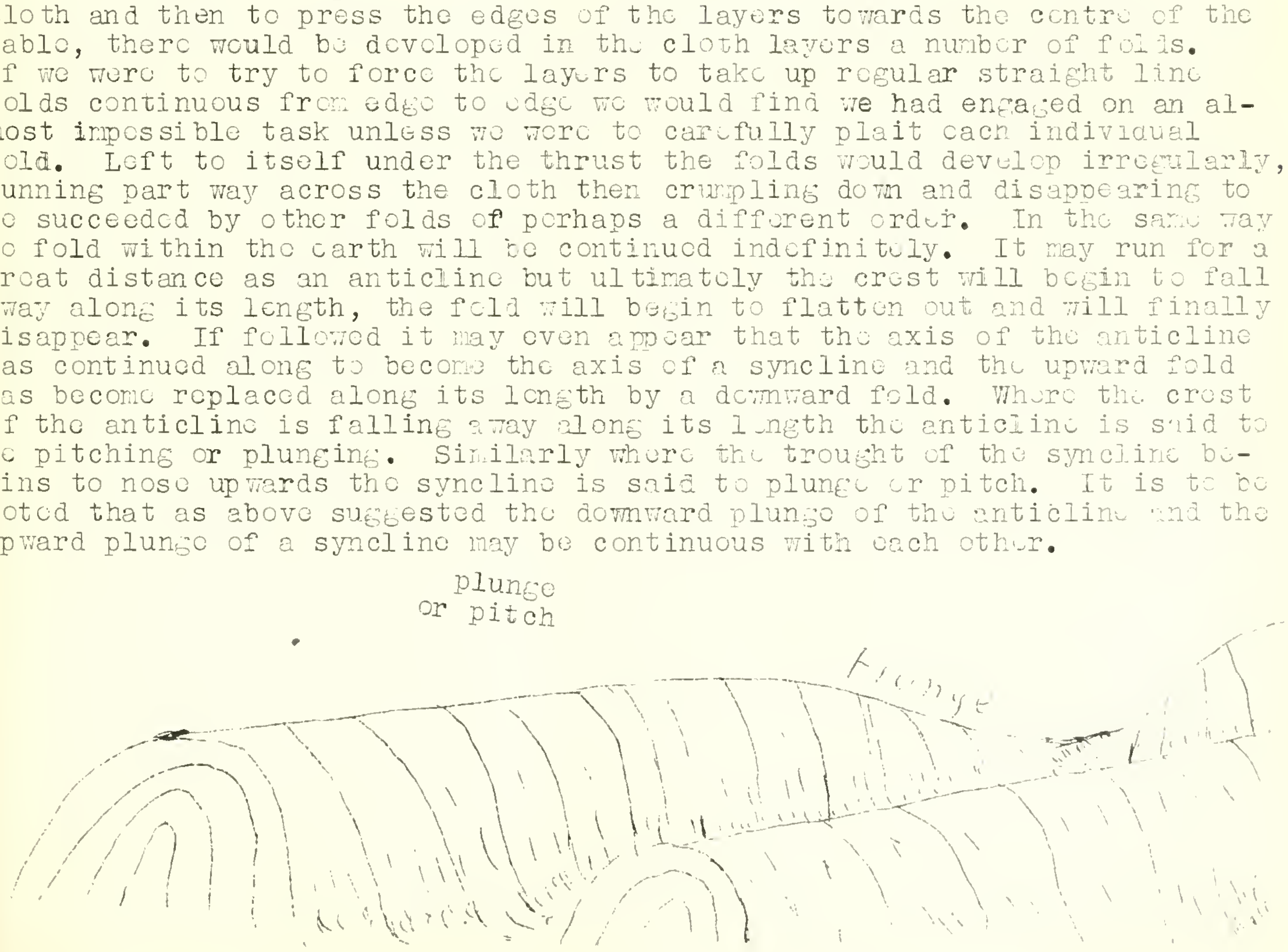


Open Anticline

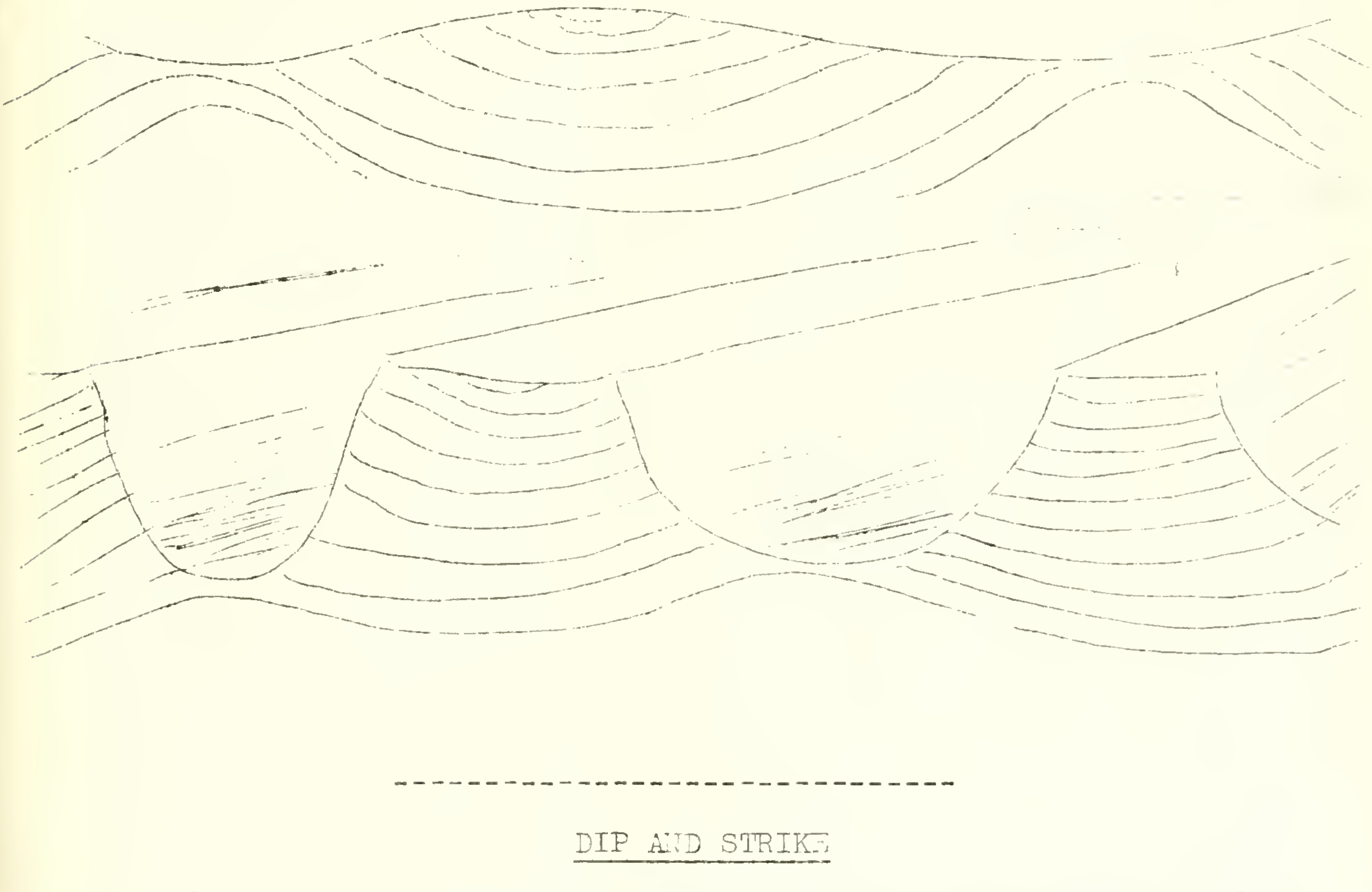


Closed Folds

If one were to place on the table a number of layers of fairly heavy cloth and then to press the edges of the layers towards the centre of the table, there would be developed in the cloth layers a number of folds. If we were to try to force the layers to take up regular straight line folds continuous from edge to edge we would find we had engaged on an almost impossible task unless we were to carefully plait each individual fold. Left to itself under the thrust the folds would develop irregularly, running part way across the cloth then crumpling down and disappearing to be succeeded by other folds of perhaps a different order. In the same way no fold within the earth will be continued indefinitely. It may run for a great distance as an anticline but ultimately the crest will begin to fall away along its length, the fold will begin to flatten out and will finally disappear. If followed it may even appear that the axis of the anticline has continued along to become the axis of a syncline and the upward fold has become replaced along its length by a downward fold. Where the crest of the anticline is falling away along its length the anticline is said to be pitching or plunging. Similarly where the trought of the syncline begins to nose upwards the syncline is said to plunge or pitch. It is to be noted that as above suggested the downward plunge of the anticline and the upward plunge of a syncline may be continuous with each other.



It is evident that the beds in the upper part of the anticline are tended to be stretched - or are in a condition of tension while the beds in the syncline will be under severe compression. These factors tend to develop cracks in the beds of the anticline and to compress the beds in the syncline more firmly. Consequently when at last the folded beds are brought to the surface and exposed to weathering and erosion the tops of the anticlines are found to be more susceptible to attack than the parts of the beds in the syncline. On account of its weakness the anticlinal section is rapidly worn down to the level of the synclinal section and quite frequently far below it, so that the position of the anticline is now marked by a valley and the position of the syncline a hill or even by a mountain.



DIP AND STRIKE

In the course of time many of the sedimentary beds were lifted up above the surface of the ocean and were exposed to the view of future observers. If these beds were uplifted without warping they would appear at the surface as they had been laid down - practically horizontal or flat lying. In this case only the upper bed of the whole series would be exposed on any flat surface, with all the others hidden beneath it. Only on the side of a hill would the edges of the underlying beds be brought to view.

In most cases, however, the beds have been more or less tilted - and - in some cases, as we have seen, very much distorted - before being brought to the surface. Where the beds are tilted from the horizontal it is

evident that at some place or other this tilt must bring the edge of the bed to the surface. The part of the bed exposed at the surface of the earth, whether on a flat plain or on the side of a hill or in a gorge, is called the OUTCROP of the bed.

If the outcrop of a tilted bed is on a flat surface, it is evident that the outcrop will be in the form of a continuous straight line. If the country where the bed emerges at the surface is rolling or hilly, it is also clear that the outcrop will not be in a straight line, but will wander from side to side as its emergence is controlled by the shape of the hills on which it outcrops.

If, therefore, we wish to follow the outcrop of a bed in a rolling country, it will be necessary to trace it step by step in all its wanderings. On the other hand, if we find a bed outcropping on a flat plain we can be sure that the line of outcrop is straight, and if we are able to find even a short section of outcrop we can project this line ahead of us and expect the outcrop to continue along its extension. For instance, let us suppose that we are following an outcrop along a horizontal plain and we come to a swamp which covers the plain and conceals the outcrop. It is reasonable to expect that if we could continue the direction of the outcrop and keep a straight line through the swamp we should be able to pick up our outcrop on the other side of the swamp in the extension of the flat plain on which we started. It is customary to call the direction of the outcrop on a horizontal plain the STRIKE of the bed. The direction of the strike is given in ordinary geographical terms as North, or Northwest, etc. It is evident on a little reflection that the line where the bed cuts the horizontal surface is the strike and further that wherever the bed cuts any horizontal plane the line formed will be parallel to the strike and any such line will give the direction of the strike just as well as the line along the surface of the earth. Because of this fact, we are able to get the strike of the bed deep in a mine as well as at the surface of the earth.

In the above paragraph we have noted that any sloping bed of rock must ultimately outcrop at the surface of the ground and that the line of outcrop on a horizontal plain is the strike of the bed. When we know the strike of a bed we are able to follow its outcrop along the flat horizontal plain, but we also noted that if the surface of the ground is irregular the line of outcrop will be wandering. The degree of wandering will depend upon two things: (1) the character of the ground; (2) the degree of slope of the bed. It is apparent that if the bed has been tilted until it is vertical, it would tend to keep a straight line across any irregular surface, but that if it was nearly flat a slight irregularity in the surface would cause the line of outcrop to shift considerably to the left or right of its course on the flat portion of the plain.

To get a better idea of the course of the bed over an irregular surface and also to know more about its position underground, it is therefore necessary to know more about its slope than merely the fact that it has a general slope towards the north or northwest, or whatever the case may be, i.e. we want to know the exact amount by which it falls away from the horizontal and the exact direction in which it falls away. This is called the DIP of the bed. Of course, it is evident that on a sloping

bed there is a slope in any direction except one, and that is the line of intersection with a horizontal plane, or the Strike of the bed. Along any other line there is some slope - very gentle near the line of strike but increasing along lines that trend away from the direction of strike until the slope reaches a maximum along a line at right angles to the strike direction. This line is the direction of Dip and the amount of dip is the angle by which the bed falls away from the horizontal in this direction. The amount of dip may also be measured in the number of feet per mile that the bed falls away from the horizontal. For example, we may say that the DIP of a bed is 27° in direction Northwest, or it may be in another case the DIP of a bed is 45 feet per mile in a direction Northeast.

FAULTING

When the thrust within and along the sedimentary beds is applied slowly and over a long time the rocks may adjust themselves to the thrust by slowly folding as previously described. In some cases the thrust is more active and the rocks cannot fold rapidly enough to keep up with the progress of the thrust. In these cases they are apt to break and the broken parts move over or against one another till the required adjustment has taken place. The breaking of the rocks - with the resulting movement is called Faulting.

Faulting is frequently associated with folding and the character of the fault is in part determined by the part of the fold with which it is associated. For instance, it has been noticed that the beds in the top of an anticline are under tension and the beds in the trough of a syncline are under compression. If, then, a break or fault occurs in the beds at the top of the anticline, the broken ends are inclined to pull apart from one another. If a break occurs in the beds in the trough of a syncline, the broken ends would tend to push past each other and overlap.

Following is a description of a number of terms which are applied to features of faulting:

Any fracture in the earth's crust which is accompanied by movement and displacement of the rock on one side of the fracture relative to the other side of the fracture is called a FAULT.

The FAULT SURFACE is the fracture surface along which movement takes place. The general plane of this surface may be called the FAULT PLANE. This general plane may be perpendicular or may be almost horizontal, but usually is at an angle somewhat intermediate between these two positions.

The angle between the vertical and the fault plane is called the HADE of the fault.

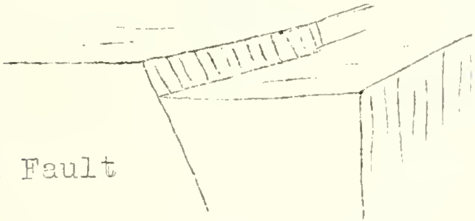
The angle between the fault plane and the horizontal plane is called the DIP of the fault. In this country we are more used to speaking of the Dip of the fault, rather than the Hade.

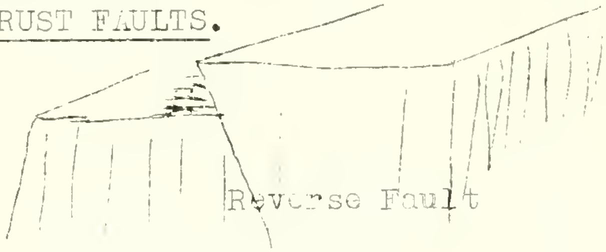
As in the case of bedding the STRIKE of a fault is in the direction of its line of emergence on a horizontal surface.

When the fault surface is sloping there are possible two types of movement relative to the slope and two types of fault are recognized in consequence. These types of movements and the names applied to the faults are indicated below.

A - The block of ground on top of the sloping fault surface may slide down. This is called a NORMAL FAULT.

B - The block of ground lying on top of the sloping surface may be pushed up and over the other block. This is called a REVERSE FAULT. It is evident that this movement is a result of thrust and the fault is also in the class of THRUST FAULTS.


Normal Fault


Reverse Fault

The terms Normal and Reverse refer to the movement up or down the fault surface. It must be noted, however, that there is often a movement along the fault plane which gives the block some displacement in a horizontal direction as well as a displacement up or down the fault plane.

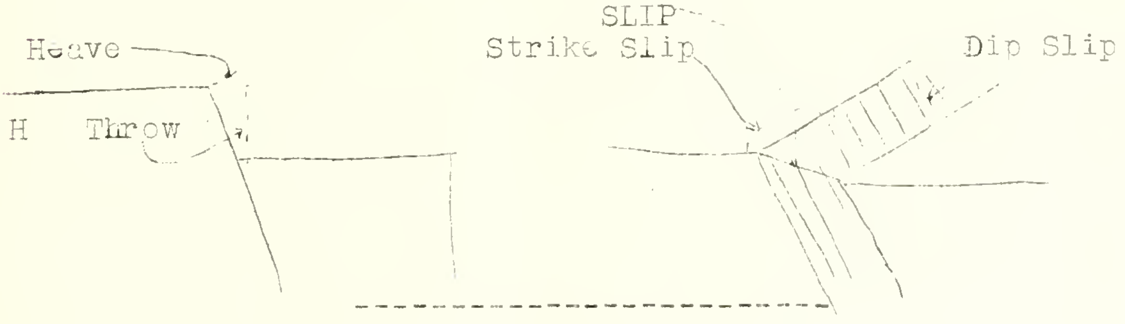
The displacement along the plane is called the Slip.

The displacement up or down the plane is the Dip Slip.

The displacement parallel to the strike of the fault is the Strike Slip.

The vertical component of displacement is called the THROW.

The horizontal component of displacement is called the HEAVE.



INTRUSIONS AND EXTRUSIONS

In ordinary excavations or in ordinary wells it is found that at a depth of 30 feet to 50 feet the temperature remains fairly constant throughout the year. A good, deep cellar is cool in the summer time and warm in the winter time, and the temperature varies but slightly through

the year. A well of the depth suggested has water which is about the same temperature throughout all seasons. This temperature is about the same as the average temperature for the year at the place where the well is located. Above the depths mentioned the temperature toward the surface increases in the summer and decreases in the winter till at the surface it reaches the ordinary daily average. At and below these depths there is no annual variation but the temperatures remain constant from year to year. There is, however, a uniform increase of temperature as we go to greater depths below this level, that is, when we descend-for, let us say 100', we find that the ground temperature has increased 1°, and in the next 100 feet there is again an increase of another degree and so forth. The rate of increase is not the same over the whole world, nor even within reasonable distances does it remain the same. In some places it is as rapid as 1° for every 60 feet increase in depth, or it may be as low as 1° for 120 feet in depth. At Kirkland Lake the rate of increase as noted in the mines is about 1° for 150 ft and in the Porcupine district it is about 1° for 200 ft. increase in depth.

It is evident that if this rate of increase is maintained, we would not get far below the earth's surface before we would encounter temperatures which would be great enough to cause the melting of any of the common rocks at the earth's surface. Apparently such temperatures do exist, but for the most part the rocks do not melt but remain solid, even at these melting temperatures. In different places and at different times, however, some of the rocks do melt and the melted rock of Magma (as the melted rock is called) migrates about within the earth's crust with a fair degree of ease, even in some cases appearing at the surface in the form of volcanic effusions. This kind of behaviour on the part of the heated rocks gives us two problems to consider:

First - Why does not all the rock melt at the temperatures which we believe are high enough to cause it to melt at the earth's surface?

Second - Why is it that at some places, and at some times some of the rock does melt, though for the greater part of the time and in most places it remains solid?

It is known that as most substances are heated they increase in volume or expand gradually with the increase in temperature until they reach the melting point, and when they melt there is a sudden expansion i.e.there is a sudden and more pronounced increase in volume as they change to the liquid state. A few substances such as Ice, Cast Iron, and Type Metal do not obey the latter part of the law, but most other substances - rocks included - do obey it and hence to melt must suddenly increase in volume.

It will be remembered that the increase in temperature - and hence tendency to melt - is reached because of increasing depth. The same increase of depth, however, also increases the load and hence the pressure on the rocks below so that with increased depth and temperature there is also a very greatly increased pressure. Now, in order to change to a liquid, i.e. to melt, the rock must expand, and if the surrounding pressure is too great for the expansion to take place, the rock will not melt at that temperature. For the rock to melt, therefore, one of two things must take place. Either

(A) the temperature must be increased so that even at the great pressure mentioned the rock will melt, or

(B) the pressure must be decreased to such a point that at the given temperature the rock may melt.

It is probable that both these factors are important in the melting of rocks. In some cases the temperatures are increased unusually, in some cases with the temperature high but unchanged the pressures are decreased and in some cases the temperatures are increased and the pressures are decreased at the same time. We may here note how these changes in temperature and pressure may take place.

A. Increase in Temperature

(1) It appears that in all rocks there are present some radio active substances and these substances are constantly giving off energy, to be absorbed in the rock in which the radio active substance occurs. Some of the energy may be temporarily transferred to other radio activity but ultimately most of the energy is transformed into heat. Blanketted under thousands of feet of cover the rock is unable to lose this heat as fast as it accumulates and in consequence the rock gets hotter and hotter until at last it reaches a temperature high enough to make it melt even under great pressures.

(2) If a strip of lead or a tough wire is taken between the fingers and bent rapidly back and forward in an attempt to make it break, it will be noted that at the place of bending the wire will become so hot that the fingers may be burned if they come in contact with that place. If the bending is slow the heating effect will not be so noticeable, but the reason for this is merely that the heat formed by one motion has time to escape before the next heating effect takes place. If the heat is not allowed to escape the temperature will rapidly increase. It may be recalled that in the adjustment of the rocks under thrust there was a great bending movement which we called folding. This bending movement must have created a great deal of heat generated to accumulate within this rock or to radiate toward the rocks adjacent to it. As in the previous case, a very heavy blanket of other rocks would inhibit its radiation to the surface and with the accumulation of heat within itself its own temperature would increase. If the original temperature were near the melting point for this depth and pressure, then the increased temperature might be just sufficient to cause fusion or melting.

(3) The gradual rise of temperature as we go deeper into the crust of the earth indicates that there must be a constant flow of heat from the interior of the earth to the outside. In most places in the earth's crust, and probably in nearly all places for the greater part of geological time, the outflow of heat from any given point toward the surface is just equal to the inflow from below, and the temperature at this point remains constant. If, however, there were at any time an extra blanket put above any layer of rock at any time, this would act as an insulator and would slow down the transfer of heat to the outside, while the same amount of heat as before would flow into the given layer from below. This would bring about a building up of heat in this layer and the temperature of the rock would increase - probably to the melting point. A situation such as this must arise wherever a thick blanket of sediments is laid down upon rocks which are already highly heated, and may be almost

ready to melt. We must remember, of course, that the addition of the thick blanket of sediments will not only serve as an insulator to the rocks below and hence increase their temperatures, but will also add to their load and thus increase the pressure upon them. The latter factor will tend to increase the temperature at which they can melt. The addition of the sediments then acts in one way to increase the temperature of the rocks with a tendency to make them melt and, on the other hand, to increase the pressure upon them with a tendency to make them stay solid. The sedimentary rocks are, however, relatively bulky, which tends to increase their weight, but increase their insulating effect relative to other rocks. Hence, it must occur that in many cases the increase in pressure is not able to offset the effect of the increase in temperature due to the blanketting factor, and in such cases the increase in temperature is able to cause the rock to melt, in spite of the great increase in pressure in the rock mass above.

B. Decrease in Pressure

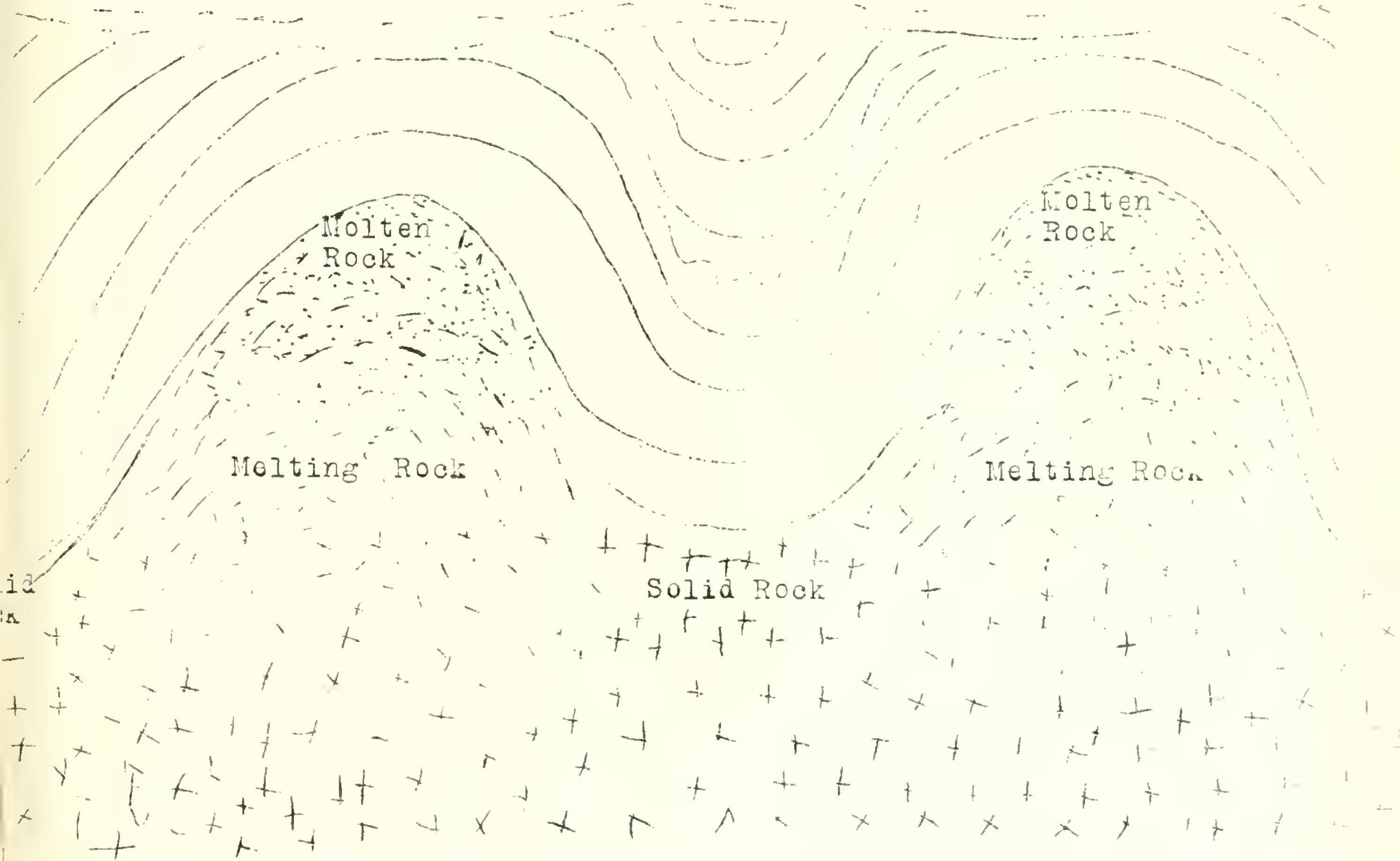
In discussing the features of folding, it was noted that the tangential thrust in the earth's crust would cause some sections of the beds to be bent upward - with a corresponding downward bending in the alternate sections - the anticlines and synclines of the folds. Before folding the beds distributed their load and the load of all the rock above them uniformly over the rocks below them. After the folds were developed, however, a great deal of this load was lifted off the areas underneath the anticlines and added to the areas underneath the synclinal sections where the load of the anticlinal arch was borne. If the temperature of the rock beneath the anticlinal arches is near the melting point for the original pressure, then the decrease in pressure may be sufficient to permit the rock to melt and as a magma to begin to rise underneath the uplifting anticline. The greater the height to which it rises, the less will be the load above it, and hence the greater the possibility of its remaining a liquid, even though the temperature may be lowered at the higher levels.

At this point there may arise the question "What causes this melted rock to rise and follow the rising anticline?" It is to be noted that the bases of the anticline (the synclinal sections) are bearing down on the rock beneath them with an increasing load. The melting point of this rock is therefore increased and there is no possibility of it becoming liquid. But, although it cannot melt, there is still a possibility that it may move without melting. Under great pressures rock may deform and may try to escape from the point of greatest pressure without ever becoming liquid. As an example of this, let us consider a common substance such as paraffin wax. Let us take a slab of this wax and place it between two boards. On top of the upper board let us place a very heavy weight and then go away and leave it under this weight for several days or weeks if necessary. On our return we will find that the wax - without melting - has squeezed downward below the weight and outward at the edges of the boards to escape from the place where the pressure is great to where it is much less. All of this it is to be noted has happened without any melting having taken place, that is, given sufficient time the solid may flow - as a solid - from place of great pressure to place of less pressure.

In the same way the solid rock under the syncline is responding to the increased load placed upon it by the arching of the folds and squeezes outward to where the pressure may be less. To the sides of the syncline -

under the anticline - the pressure is much less and to these places the solid rock is pushed. Here it creeps under the melted rock which has already liquefied under the relief of pressure as noted before. But the new, solid, rock - also very hot - in its turn responds to the relief of pressure under the anticline and also melts, pushing up the rock already melted above it. In this way the rock under the synclines is being squeezed toward the anticlinal areas where it melts and moves upward toward the arch of the anticline. Hence, as long as the thrusting and folding continue the rock may continue to migrate from beneath the synclines to positions beneath the anticlines where it may melt and move upward. When the thrust is exhausted the uplift of the arches ceases, pressures are again equalized, and the upward migration of the magma is halted.

It is not to be understood that under every anticline there is to be found molten rock working its way from the greater depths towards the surface. It is only where the rock beneath the folding area had already approached the critical temperature of melting that the added heat of folding and the relief of pressure under the arches would permit melting and the subsequent migration of the magma or melted rock upward in those places.



From the foregoing discussion of the factors that tend to bring about fusion in rocks, it is evident that increase in temperature may be brought about by (a) a blanketting of heated rocks by the addition of sedimentary load above them,or(b) by a development of folding in the area adjacent to them, and that (c) a decrease in pressure may be brought about in the anticlinal sections of the folded areas. All of these factors are characteristic of the regions of the earth where the debris of the continents are piled up on the ocean floor, and it is interesting to notice

that the regions of folding and faulting are also in many cases the regions where magmas are developed and where volcanic belts occur. There may be other factors in operation as well as the factors of loading and folding, but in any case the effect of these latter must be very important contributors to the melting of the rock.

In the preceding discussion of intrusions and extrusions much attention has been paid to the effects of loading and folding in the sedimentation belts of the earth's crust, but it must not be concluded that the fusion of rocks and the migration of magmas does not occur elsewhere. It is thought that the insulating effects of the continents as a whole do permit, from time to time, sufficient accumulation of heat underneath them to cause the very deep seated, basic rocks to melt and the liquid rock so formed - or part of it - may find openings extending to the surface over which it may flow in enormous quantities. The overflow or other migration of the melted rock permits the escape of the accumulated heat and the underlying rocks may again cool to the temperature of solidification. Such meltings, migrations and overflows occur at various places in the earth's crust which do not seem to have any apparent relationship to the continental margins or to the zones of folding.

It may be that in its movement upwards the rock never reaches the surface, but comes to rest at great depths where it cools slowly and solidifies in the form of large domes and ridges which may be only exposed at the surface after long ages of weathering and erosion have removed the strata which originally covered them. These domes of igneous rock with an indefinite and unknown base are known as BATHOLITHS. The rocks which form batholiths are usually of the granitic or acidic type and the texture of these deep seated rocks is granitoid.

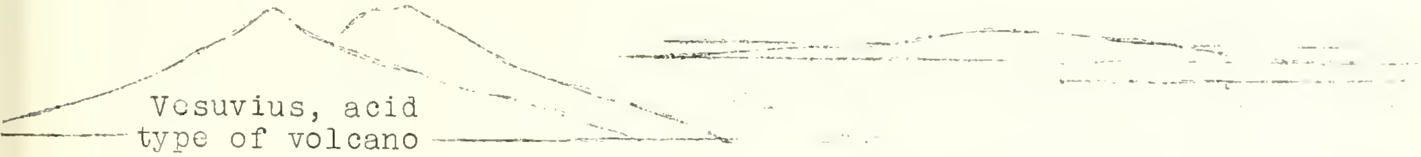
In some cases the magma may reach the surface and ultimately break through to pour out as lavas from the opening that the upwelling rock has made. The outflowing lavas tend to pile up around the vent and so build up a conical mass of solidified magma. From the centre of the cone more molten matter may from time to time be erupted to add to the mass already accumulated. This structure is called a VOLCANO.

The shape of the volcano and its behaviour at the time of eruption are determined largely by the character of the magma which is being emitted. Magmas of the granitic or acid type are rather viscous and hence have a sluggish flow. They also have a large amount of water and other gases in their composition which at the great pressures of depth are an intimate part of the general solution of the silicates (felspars, ferromagnesians and quartz). When the magma rises to the surface, however, the pressure is so reduced that the superheated water tends to expand as steam and to escape from the solution. The viscous nature of the magma. however, prevents easy escape and in consequence the whole upper part of the magma, at or near the surface, often explodes with great violence, blowing away the adjacent rocks and disrupting the magma itself into an infinite number of particles. These particles may range in size from masses of molten lava a foot and more in diameter to blebs of an inch or so down through drops and droplets to the finest lava spray. These particles may chill in the air and later fall as BOMBS - the larger masses, LAPILLI - the drops and droplets, and DUST or ASH - the solidified spray. Some of the dust may be so fine that it may remain in the air for days or even years. The greater part of the dust probably falls within a few days

of the explosion and the amount of dust is often so great that it may pile up to a thickness of many feet in the area surrounding the volcano and this area may extend to more than one hundred miles from the source. The dust may fall either on the sea directly or on the land from which it is ultimately washed into the sea. Mingled with the finer dust - especially near the volcano - will be a number of larger fragments which have been blown far enough away to mingle with the finer air-borne dust. This accumulation of volcanic dust when solidified into rock is called TUFF. The tuff is generally more or less stratified and is usually characterized by the inclusion of some of the larger angular fragments in the finer-grained groundmass formed from the fine dust.

Following the first explosive activity the magma may well over the lip of the opening in a more gentle fashion. Much of the steam and other gases may escape in the explosive manner already mentioned, but in many cases there is left in the magma an enormous mass of gas which expands more gently in the magma as the lava pours forth. The intimately disseminated gas expanding in the viscous lava swells it into what is practically a lava froth and as such it flows from the volcano to later freeze or solidify as a rock froth which we call PUMICE. When most of the gas has escaped from the lava below the latter may continue to well up and overflow to form lava sheets which when solidified form rocks which we know as rhyolite, trachyte, andesite or basalt - according to the mineral content of the magma from which they were derived. The more basic of these lavas rarely have the more explosive phases which have been described above and which find their cause mainly in the viscous nature of the acid type of lavas, in addition, of course, to the large amount of gases which they may contain.

On account of this viscous nature of the acid lavas they tend to flow sluggishly and hence to pile up about the vent of the volcano in very steep cones. On the other hand the basic magmas tend to melt to a liquid which flows much more freely than the acid type. On account of the lower viscosity of these basic magmas any gases that are present may expand and escape fairly freely and hence when the magma reaches the surface to overflow it usually escapes without the violent explosive activity of the acid type of volcano. Furthermore, since it flows so freely, it does not pile up steeply about the vent but spreads rapidly away from the outlet to form a low and gentle cone.



Mauna Loa with Vesuvius drawn to same scale (at left)

In the preceding paragraphs we have been considering those manifestations of magmatic migration in which the magma has made its way to the surface to break forth and overflow as a volcano. This volcanic activity is very obvious surface manifestation of the melting and movement of the rock from below and the surface manifestation is contemporaneous with the period of melting and migration of the rock at depth.

It is probable that although this surface volcanic activity is so obvious, it represents only a very small fraction of the movement of the igneous rocks. Far below the surface and at the other extreme are those masses of magma which migrated but a short distance from their place of melting into the arches of the uplifted rock which overlay them. There, on the cessation of the earth movements which gave them birth, they stagnated and cooled and solidified to form the BATHOLITHS already mentioned. The rock in these batholiths, it has been noted, is most frequently of the granitic or acid type. The acid magma is viscous and sluggish in its movements and hence does not move freely or flow readily into smaller openings at great distance from its source. The more liquid magmas, however, may migrate considerable distances from their sources and may insinuate themselves into small openings which would resist the entrance of the more pasty acid magma. These basic, molten rocks may come up from below in fairly narrow cracks in the earth's crust and at some point in the higher levels may be able to lift up the whole of the upper layers of rocks and at this level under run them for great distances on either side of the crack up which they have been welling. In this way the magma acts as a liquid wedge, thrusting itself laterally from its vertical channel and forming an injected layer of molten rock between the two layers of rock which it has spread apart. This layer may extend outwards on all sides of the source channel or on one side only. It may be relatively thin or it may spread the older rocks very widely apart and be of great thickness as well as of great lateral extent. On the other hand, it may merely dome the rocks above it without spreading very far on either side of the vent which carried it up from below, so that the resultant form has a flat base and a fairly steeply domed top. These molten masses solidify quickly since the layers are relatively thin and the colder rock into which they have injected themselves soon absorbs their heat.

The main vertical (or nearly vertical channel) which carried up the magma may continue up to the surface near which it may be arrested or where it may break through to form a volcano. In addition to this main vertical channel there may be smaller and minor vertical channels arising from it or given off from some of the lateral injections below. The magma in these vertical channels, as in the horizontal layers, chills and solidifies fairly quickly to form solid walls of igneous rock running through the older rocks which they transgress.

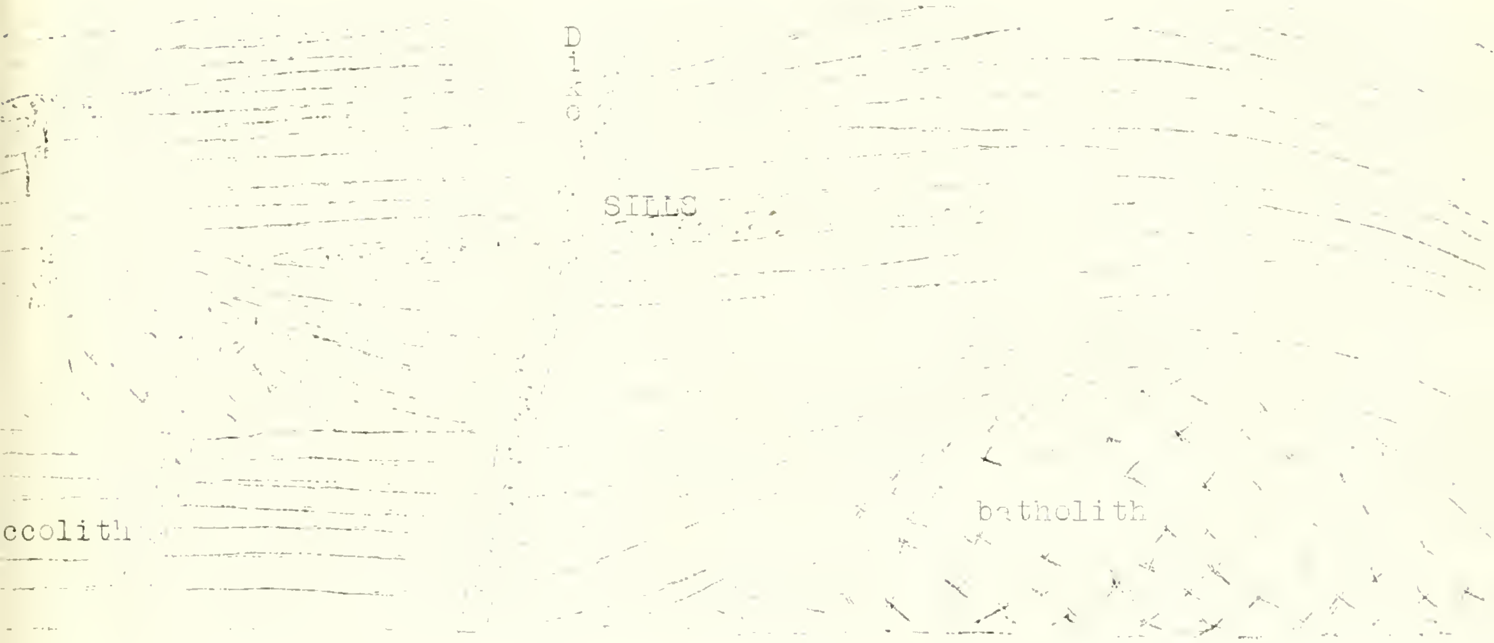
Through weathering and erosion the older rocks which lay above and around these injected rocks may ultimately be removed and the intruding rocks may be exposed or revealed at or near the surface of the earth. According to the manner of the intrusion and the form which the magma has assumed on cooling, different names are given to different injected bodies although all of them may be from the same magma and of the same type of rock.

The vertical walls of injected rock, with great horizontal length compared to their width are called DIKES.

The horizontal bodies with great lateral extent compared to their thickness are called SILLS.

The more restricted bodies of intruded rock spreading out horizontally at the base but domed on the upper surface are called LACCOLITHS.

Large bodies of igneous rock in the form of domes or ridges with an indefinite and unknown base are called BATHOLITHS.



We may now summarize the different types of rocks formed by the freezing or solidifying of the magmas at different places - at the surface or at different depths under the surface.

A. Extruded at the surface.

B. Intruded below the surface into narrow openings with walls close enough to cause fairly rapid cooling but not as rapid as in the case of lavas at the surface.

C. Cooled at great depths in large bodies where cooling was very prolonged and the crystals formed very slowly.

A. Extruded at the surface

(1) From the explosive type of volcano the bombs, other fragments and fine dust may accumulate to form a rock composed of irregular fragments of volcanic origin and of various sizes. This rock is called an AGGLOMERATE.

(2) The finer dust with occasional fragments of different sizes which have dropped into it is called TUFF. It is probable that much of the material in the tuff has fallen directly into the water or has fallen on the land and is later washed into the water to be deposited there. Thus, much of the tuff that we now find is really water laid and hence, although it is a rock whose fragments were of immediate volcanic origin it was, in many cases, really deposited as a sediment.

(3) In lavas of the acid type the dissolved gases may expand just as the liquid rises in the neck to overflow - not violently enough to cause an explosion but with sufficient expansion to cause the whole lava to expand into a flowing lava froth. On cooling this forms a rock froth called PUMICE.

(4) At the overflow the rock solution or lava may lose most of its gases and then be cooled so rapidly that the minerals have no opportunity to gather themselves into crystals of even the finest dimensions and the frozen lava is just the same as the completely liquid lava with the exception that it is solid instead of liquid, that is, it is a solid solution of the lava and is called a GLASS or OBSIDIAN.

(5) When the lava overflows in larger sheets and cools more slowly the crystals may begin to form and to grow throughout the mass. Some of the crystals may have had an earlier start in their forming (they may have even begun in the neck of the volcano) and these crystals will be somewhat larger than the general mass of crystals in the solidified rock.

Since lavas of the type (5) above contain recognizable crystals they may be related to their deeper seated relatives and are called RHYOLITE, TRACHYTE, ANDESITE, or BASALT according to their mineral composition. Their relationships will be noted in the table to follow.

In most cases the lower part of the lava flow will have cooled more slowly than the upper part and the crystals in this part will be coarser than in the lava above. In addition to this difference the gases which have escaped from the lower and hotter part of the lava may become entrapped near the surface giving a vesicular appearance to lava near the surface. This irregular texture of the upper part of the flow is accentuated by the ragged and broken top formed by the flowing and breaking of the freezing surface.

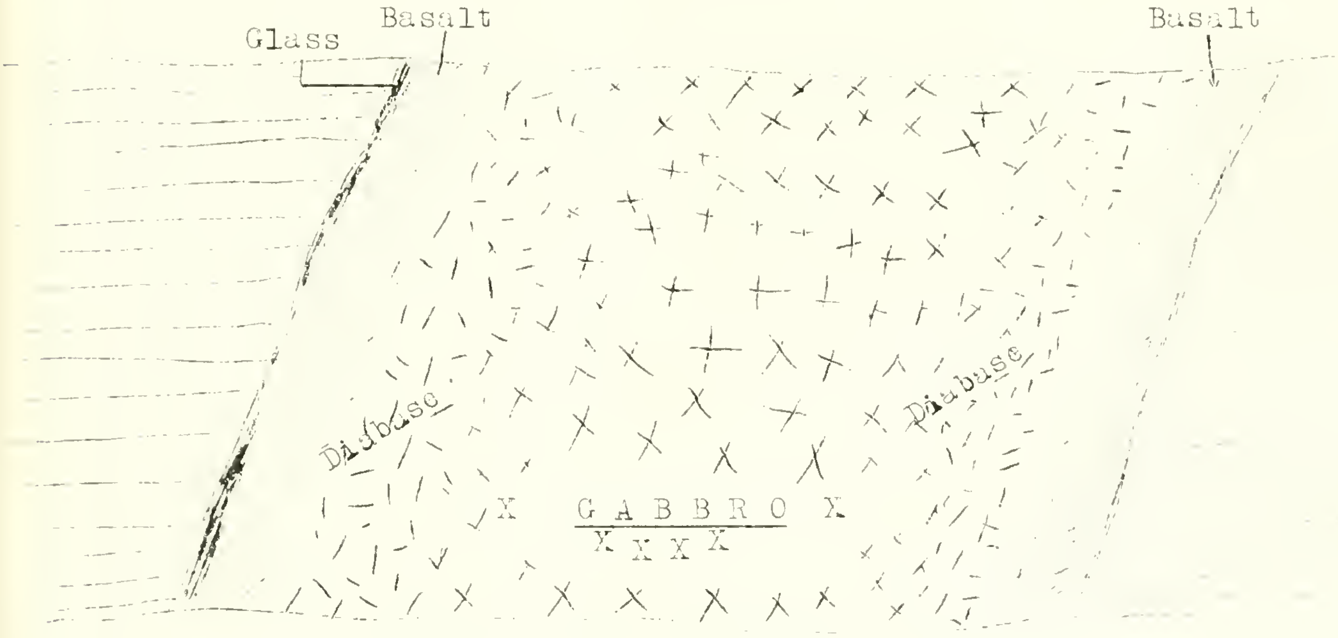
B. Rocks which as magmas were injected into relatively narrow openings and chilled to form sills and dikes.

In these cases if the opening is very narrow the magma chills [illegible] quickly throughout and the crystals do not have time to grow to any great size, so that most of the crystals of the rock are small. In some cases, however, there are some of the crystals that seem to have had an earlier start in their formation and these may grow to larger sizes. The resulting rock will show a number of larger crystals embedded in a mass of smaller crystals. This texture is known as the porphyritic texture and the name PHENOCRYST is used to designate the larger and better formed crystals usually isolated from each other and embedded in the general ground mass of smaller crystals. The names of the rocks which have been formed under these circumstances have been given in the table on page 8 of these notes and will be repeated in a table to follow.

It may be thought that the description of the texture of the porphyritic rocks as given is very similar to that of the lavas of "A" above and that there might be difficulty in distinguishing these rocks. In some cases this is so but usually the larger crystals of the lavas have been so corroded by the heat and the rough treatment of the flowing lava

that they have lost the clean cut outline which is usually characteristic of the phenocrysts of the porphyritic rocks.

In some cases a sill or dike may be so large that the magma at the centre may be unable to lose its heat very rapidly and hence cools so slowly that its crystals grow just as in the deeper seated rocks and the rock at the centre of such a body has a granitoid texture, which grades through finer and finer textures to the walls of the intruded rock at the contact with which it may even form a thin margin of glass. An example of this is indicated in the sketch below.



C. Rocks which were formed by the cooling of very large masses of magma at great depths. Owing to their large masses and to the great cover over them these magmas cooled very slowly and as noted before formed rocks of granitoid texture. The names of these rocks are noted in the table.

Mineral Composition	Intruded & cooled at great depth	Intruded into narrow channels	Lavas poured out at the surface		
Quartz) Orthoclase) Hornblende) or Biotite)	Granite	Quartz Porphyry Granite Porphyry	Rhyolite	Obsidian	Pumice
Orthoclase) Hornblende) or Biotite)	Syenite	Porphyry Syenite Porphyry	Trachyte	Obsidian	
Plagioclase) Hornblende)	Diorite	Plagioclase Porph. or Porphyrite Diorite Porphyry	Andesite		
Plagioclase) Pyroxene)	Gabbro	Diabase	Basalt		

We may now consider some of the factors involved in the solidification of the magmas to form rocks and to note some of the products or by-products of the freezing which do not always appear in the rock itself. Before proceeding with this discussion we may diverge to consider for the purposes of illustration the behaviour of some artificial rocks of our own manufacture.

Let us take first some common salt, compacted to form a rock like mass, and heat it gradually in an attempt to melt it. We would find that we would have to heat it to a very high temperature (about 1500° Fahrenheit) before it would become liquid.

If we were to make our artificial rock of common granulated sugar and repeat the experiment we would find that at a much lower temperature (about 350° Fahrenheit) the sugar "rock" would become liquid.

Let us now make another rock - this time of about equal parts of salt and sugar, finely ground and intimately mixed with each other, and compacted to form a solid rock. Let us heat this rock as we did the others in an attempt to melt it. At about 350° the sugar in the rock will have melted and the probability is that in this melt some of the salt will begin to be dissolved so that long before we have reached the temperature of 1500° (the melting point of the salt) all the salt will have been dissolved and we will have a complete melt or solution. In this case the presence of one substance has helped to bring the other into solution or to melt at a temperature well below its own melting point.

If we were next to add even a very small amount of ice to the salt-sugar rock, and then heat the mass until it was all melted, we would find that the melting temperature was lowered still further. The three substances have interacted with each other to help bring each other, and hence the whole mass, into solution or to melt.

Similarly in rocks the presence of different minerals helps to lower the melting point of the whole mass and if in addition to the silicate minerals (quartz, felspars and ferromagnesians) we have also some other materials such as water (steam?) carbon dioxide and other gases, the melting point of the magma will be still further lowered.

In the preceding pages in our discussion of rocks we have considered only those minerals which were present in most abundance and whose presence determined the character of the rock - namely Quartz, the Feldspars and the Ferromagnesian minerals. In the original fluid magma there were, however, a number of other constituents which may now be mentioned. Nearly every magma or hot solution of the rock contains a greater or less amount of water, probably from one percent to five percent or more. The present solid, deep seated rocks are known to contain even this much, but the amount that escaped in cooling (or that may have been added afterward) we do not know. It is probable, however, that the rock lost more in cooling than it has gained since and that the water in the magma was much in excess of the water that we now find in the solid rock. In addition to this water (or steam) in the magma there are usually a number of other gases - carbon dioxide, sulphur gases, chlorine gases and so forth. Most of these gases probably helped in the solution of the silicate minerals so that the temperature of melting - and hence also later of freezing - would be much lower than if they had not been present.

Besides the gases and the silicate minerals there are usually in the magma small amounts of other elements or minerals. There may be a great variety of these other substances present, but we shall here mention only a few in which we may later be interested. Some of these elements are: Copper, Gold, Molybdenum, Silver, Sulphur, Tellurium, Tin, Tungsten, and Zinc. There are still others which we may need to mention later, but these will serve for purposes of illustration at present. Let it again be emphasized that when these elements, or their compounds, are present in a magma they are usually present in very very small amounts, usually in the order of the smallest fractions of an ounce per ton of magma or rock.

Let us now note that the magma may contain the following groups of materials:

(1) Silicate minerals - such as Quartz, Feldspars, and Ferromagnesian minerals. These minerals make up nearly the whole of the magma

(2) Water or Steam and other gases - such as Carbon di-Oxide, Chlorine, Fluorine, Sulphur gases and so forth. These may probably make up to as much as five per cent or more of the magma.

(3) Other minerals in smaller amounts - such as minerals of Chromium, Copper, Gold, Silver, Sulphur, Tellurium, Tin, Zinc, and many others. When present these elements are present in only very small amounts and some of them apparently in such minute quantities that it is only after very much concentration from parts of the magma and then by later artificial concentration of the natural concentrations that we are able to recognize them at all.

At this point let it again be noted that the steam and other gases of the second group are very effective in aiding in the melting or solution of the minerals of the first and third group, and since the minerals of the third group are present in such small amounts the water and other gases will be able to keep most of the minerals of the third group in solution long after the great mass of the silicates has been cooled to the point of freezing or solidification.

THE COOLING AND FREEZING OF MAGMAS

Having considered in the preceding pages the factors and features associated with the melting and migration of magmas, let us now deal with the latter end of the processes - the cooling and freezing or solidification of the magmas.. For this purpose we shall consider the cooling of a batholithic mass to illustrate the principles that we wish to discuss in dealing with the consolidation of magmas, in general.

When the magma in the batholith comes to rest and begins to cool, it is obvious that the cooling will most likely begin at the outer and upper surface. In time the outer margin will be sufficiently cool that crystals of the silicate minerals will begin to form on the inner surface of the containing rock and these will continue to grow until the whole of this surface is lined with a layer of the silicate crystals. This layer in turn will cool and will grow on its inner surface another layer of crystals. Continued cooling will produce an ever thickening zone of crystals or solid rock (of the silicate minerals - Quartz, Feldspar, and a Ferromagnesian mineral). Inside of this ever thickening layer will be the magma which is still liquid. In the outer zone of solid rock the

crystals will have grown so closely together that there will be practically no liquid material left among them - nothing but the silicates which have been forced to solidify at the decreasing temperatures at the outside of the batholith.

Let us note that since it is the silicates only which are forming at the outside and withdrawing from the general magmatic solution then in the residual magmatic solution which is retreating toward the centre of the batholith there is a decreasing amount of the silicates but the amounts of the gases and the minor minerals will remain practically unchanged. With continued freezing of the silicates the residual liquid, therefore, becomes relatively richer and richer in the proportion of the water and gases to the remaining silicates, and hence it will have a much greater fluidity than the original magma.

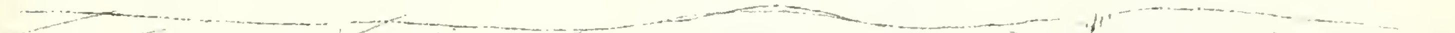
In the latter phases of the cooling of the magma we will have the greater part of the batholith solidified, but near the base there will be segregated various pools or cisterns of a very fluid solution containing in localized spaces all the water and other gases that were originally disseminated through the whole magma. Concentrated to saturation in this solution will be the silicates not yet solidified, and, dissolved in it also, will be all the minor minerals of the third group which have been squeezed away from the freezing silicates and crowded to the centre with the aqueous part of the magma.

After the batholith has been completely solidified - with the exception of the small liquid residual pools near the base - it may happen that a crack may penetrate into the mass. These cracks may be caused by the cooling and shrinking of the batholith after solidification or they may be due to larger earth movements. Whatever may be the cause, these openings frequently occur and in some cases their course causes them to break into some of the segregated pools of liquid already referred to. The liquid is under great pressure and as soon as an opening is offered it gushes through it into the upper levels of the batholith and beyond it into the overlying rock. This solution is very fluid and is able to penetrate into the tiniest openings that occur in its path. Under the lower conditions of temperature and pressure that prevail in the upper levels the solution cools, loses some of its liquids in the form of escaping gases and precipitates the solids that were held in solution below. The chief solids that are precipitated are crystals of quartz and felspar but in this very fluid solution crystals grow to a much greater size than the crystals in the main batholith. In the latter case the magma or solution was in the main a melted silicate solution with a little water. On this account it was quite viscous, even at high temperatures and internal movement of the particles was somewhat restrained so that the crystal centres only drew from a limited range for their supplies and hence no crystal could grow to a very large size. In the residual liquid which was later injected into the narrow cracks in the upper part of the batholith and surrounding rocks the silicates were held in solution with a relatively large amount of aqueous liquid and the solution was quite fluid. The particles could more freely migrate in this fluid and thus each crystal could draw its supplies from a larger area and grow to be quite large. In the dike like boey formed in such manner the crystals are characteristically very large and their margins well defined. The dikes or dike like bodies formed in the manner just described are quite character-

istic of the last stages of a granitic batholith and are easily identifiable from the dikes formed by the intrusion of more viscous magmas. They are given the name PEGMATITE dikes. On account of the very fluid nature of the material ejected from the batholith in this pegmatitic stage the pegmatitic material is able to enter the very smallest cracks in the rocks so that we may have pegmatite dikelets ranging down to the fraction of an inch in width or thickness.

We noted in the preceding paragraph that the chief materials in the pegmatite body will be the large crystals of silicate minerals - quartz, felspar, mica, etc. In some pegmatites, however, there may be found small proportions of the elements and minerals from class 3 previously mentioned, e.g. Molybdenum, Tin, or Tungsten. It is probable that the silicates will be precipitated through the whole length of the pegmatite dike and so may be found wherever the dike is later exposed by weathering and erosion. On the other hand the rarer minerals of the solution, present in only small amount will probably be more selective in their place of solidification from the solution and will likely be found in a restricted zone or stretch of the dike.

In some cases the amount of tin, tungsten, molybdenum or other metals or minerals in these sections may be sufficiently large to permit mining of the dike for their recovery.



Before leaving the discussion of pegmatite dikes it may be interesting to note the effect of the dike solutions on the rock adjacent to it. At the high temperatures and pressures in the solution the fluid , liquid or gaseous, is very corrosive and the corrosive gases (called mineralizers) penetrating the rocks near the dike cause them to be very highly altered. Even the granite - the parent rock of the dike solutions - is itself very much modified when this solution later invades it. The altered rock on the sides of the dike is called Greisen and this greisen is a rather characteristic feature of the country rock of the pegmatite dike.

METAMORPHISM

In the early part of the work mention was made of the fact that rocks could be classified into three groups: the Igneous, the Sedimentary, and the Metamorphic. We have already dealt with the igneous and the sedimentary rocks and we may now deal with the metamorphic rocks and some of thephases of metamorphism.

By Metamorphic Rocks we mean those rocks that have been so changed from their original forms (either igneous or sedimentary) that they no longer resemble the parent rocks or are at least so different from them that they are easily distinguished from the rocks from which they have been derived.

By Metamorphism we mean (in geology) the processes of changing minerals or rocks or by which changes are brought about.

To be strictly correct, we should say that practically all rocks near the surface of the earth are undergoing metamorphism as they are slowly changing by weathering or consolidation to form some different type of rock or mineral substance. In a more limited meaning, however, it is customary to speak of metamorphism as going on mostly at greater depths in the earth's crust where the pressure and movement accompanying earth adjustment is modifying the rock structure to a greater or less extent and the increased heat together with escaping solutions from migrating magmas is bringing about a change in the mineral content of many of the rocks within range of the invading magma.

The type of metamorphism which results from the heating of rocks by magmatic invasion or from the chemical alteration brought about by the injection of infiltration of gases or solutions from the magmas into the adjacent rocks is called CONTACT METAMORPHISM. This kind of alteration in the neighbouring rocks is naturally rather limited in its extent being confined to the relatively narrow limits to which the heat and magmatic juices of the liquid rock can penetrate.

On the other hand the thrust and pressure developed in periods of earth adjustment is very effective in producing certain changes in the rocks and as this pressure is extended over very wide areas the rock changes which it may produce are very widespread in their distribution. On account of the widespread nature of its effects this type of alteration is referred to as REGIONAL METAMORPHISM.

Regional Metamorphism

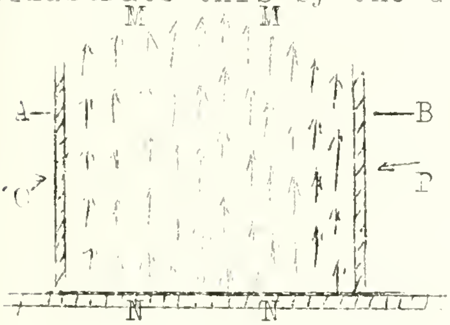
Let us consider first the latter type of alteration - Regional Metamorphism. This kind of alteration it has been noted is due to the development of great pressures in the earth's crust. Now if a mass of rock is subjected to greatly increased pressure it may try to respond to this thrust in one or both of two ways: (A) It may tend to decrease its volume in some way; or (B) It may try to move away from the direction of greatest pressure along lines of lesser pressure. It has already been noted that under great pressures rocks may flow and it is obvious that in its flow some alteration must be taking place in the relations of the crystals or grains of the rock to each other, thus the structure of the rock may be

somewhat different after flow than it was before.

The sedimentary rocks on account of their stratification and of their relatively high porosity often show the marks of these changes more effectively than the igneous rocks and we will first consider the ordinary sedimentary rocks, shale, limestone, sandstone.

Shale, as has been noted, is made of muddy sediments which are largely composed of kaolin (an aluminium silicate) with smaller amounts of finely divided quartz or silica and small portions of lime, iron, potash which have fallen down with the mud or become entrapped in it. The greater part of the shale, however, is made up of the mud which is largely kaolin. We will discuss briefly the effects of differential pressure on this type of rock.

When excessive pressure is applied to this type of material the tendency is for the material to flow away from the points of greatest pressure to regions where the pressure is less. An attempt is made to illustrate this by the diagram below. We will suppose that a mass of clay or plasticene is confined between the walls A and B which are moveable back and forward between O and P. It is not confined upward toward MM. If now pressure is applied between P and O and the sides A and B made to move toward each other, then the only escape for the plasticene or clay is upward MM. Movement near A and B is somewhat constrained by the friction with these walls and at the centre it will be much more free. Hence the central particles will move much more rapidly than the particles in the layers to the outside of them and these more rapidly than the layers still farther out and so forth, i.e. there is differential movement of the particles in the various layers and hence sliding planes are apt to be developed in them. These sliding planes will be in direction NM or at right angles to OP - the direction of the application of the pressure.



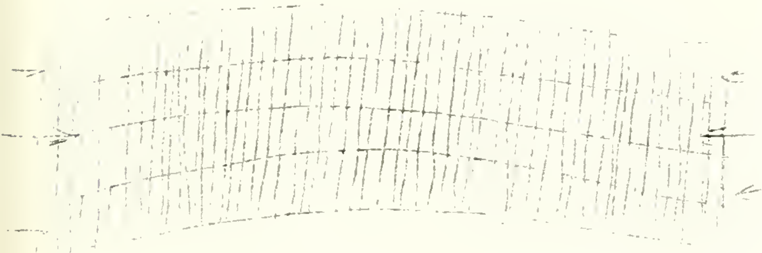
The same type of movement develops in the particles of the shale when it is subjected to differential pressures in the earth's crust. The particles tend to move at right angles to the direction of greatest pressure and hence to develop sliding planes so oriented that they are normal to the direction of pressure.

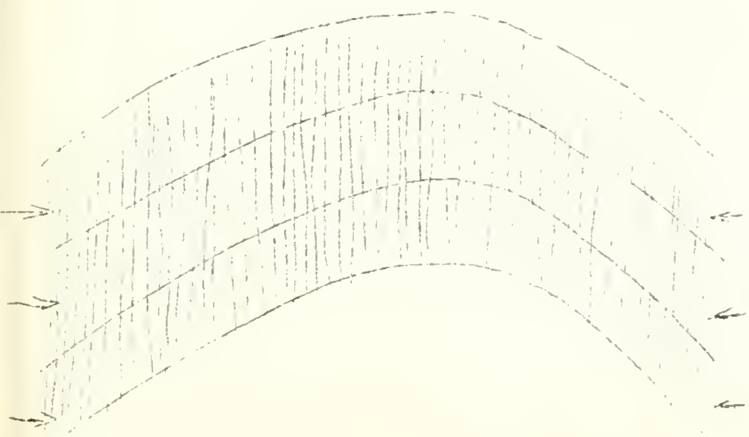
Furthermore, if there are in the mud or shale any minerals or particles of a flattened or flake like shape they will not tend to set themselves across the lines of flow but rather parallel to these lines or planes thus accentuating the tendency to develop, in the shale or mud, planes or surfaces of potential parting at right angles to the direction of thrust.

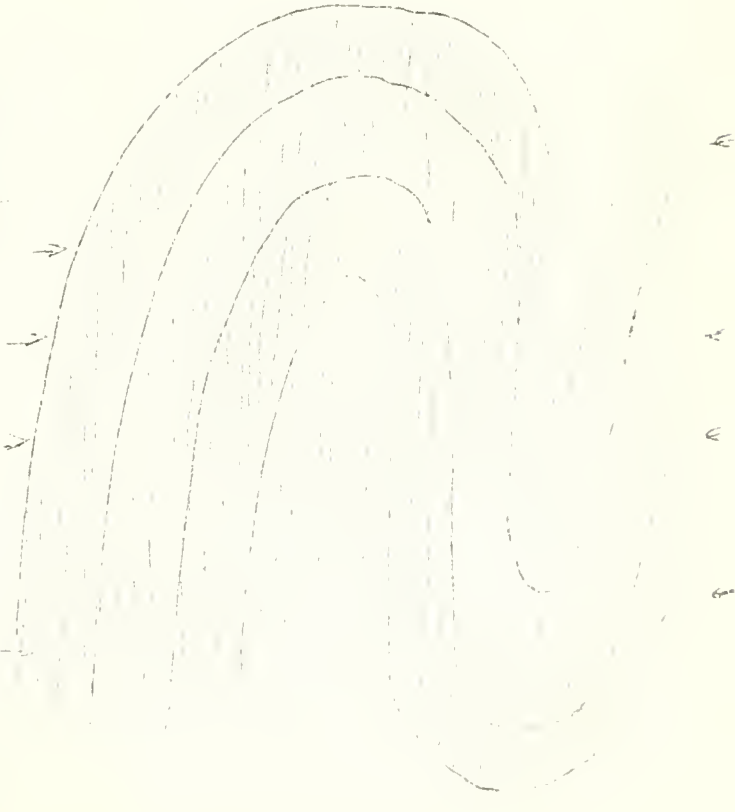
The great pressure is also tending to reduce the volume of the shale or mud in any way that this may be accomplished. Because of this factor much of the water that was present in the shale is expelled and the whole mass is much more compacted than it was before the pressure was applied.

After the modification of the rock has been accomplished it will no longer appear as the shale it was before but as a much more compact rock with planes of potential cleavage well developed. This type of rock, developed from shale. is called SLATE. So well compacted is the rock that the slaty cleavage planes may not be apparent in the freshly quarried rock but they ultimately become apparent on old weathered exposures or may become evident when the blocks of freshly quarried rock are split.

In speaking of folding and faulting we noticed that the great thrusts developed in the earth's crust during periods of crustal adjustment were usually parallel the earth's surface or nearly so. It is largely due to these thrusts that slates are developed and hence it follows that if the slaty cleavage is at right angles to the thrust the cleavage must be at right angles, or nearly so, to the earth's surface, that is it mustbe vertical or near the vertical position. This, of course, is in most cases at right angles to the bedding and as a result of the slaty cleavage and of the movements of the particles which caused it the cleavage in most cases obliterates or makes the original bedding planes and also tends to destroy or distort any fossils or other sedimentary features which were originally present in the shale. In some cases the traces of the original bedding can be seen traversing the cleavage planes and as remarked before it is usually at right angles to the cleavage. In some instances, however, the beds may have been on the flank of a fold and hence were not parallel to the earth's surface but inclined to it. In such cases it is probable that the slaty cleavage will not be at right angles to the bedding and in a close folded anticline, in fact, the bedding planes and cleavage planes on the flanks of the anticline would be parallel to each other.







The development of slaty cleavage is common in such rocks as were originally made from clay or rocks having a high clay content since in such rocks the particles tend to flow more freely. In a rock such as limestone the reaction to compression may be shown in another way. As originally deposited the limestone was made up of an infinite number of very fine particles of lime or calcium carbonate ($CaCO_3$ or $CaO.CO_2$). In addition there was present - as there is present in all rocks - a variable amount of water. This water may simply form a very thin film on the surface of each particle or it may also fill up a number of the pores in the rock but in any case all rocks - even the igneous - contain water in greater or less amounts. With the assistance of the contained water the small particles of lime begin to reform themselves into small crystals. These have the chemical composition of the lime as noted above and the crystallized lime carbonate is called Calcite. The form of the crystal is such that it is about equally developed in the three dimensions and when pure it is white or crystal clear in colour.

As noted before, one of the tendencies of a rock under pressure is to reduce its volume and in the case of limestone this can be in some measure accomplished by consolidating large numbers of small crystals into a smaller number of larger crystals, each large crystal taking up less space than the aggregate volume of all the smaller crystals which went to make it up. Hence the total volume of all the reorganized large crystals in the rock is smaller than before the consolidation took place. By this recrystallization the limestone is changed to a CRYSTALLINE LIMESTONE or MARBLE. The term crystalline limestone is not as distinctive as it might be since even the ordinary limestone as it was at first was crystalline, but the crystals were so small that they were invisible to the unaided eye.

As in the case of the mud rocks it is probable that there were some flow lines developed in the metamorphism of the limestone but the growth of the large crystals of calcite, with their equi-dimensional shape, was so great as to destroy all evidence of flow lines even as it destroys the evidence of finer bedding and lamination and all traces of fossils that may have been in the original limestone.

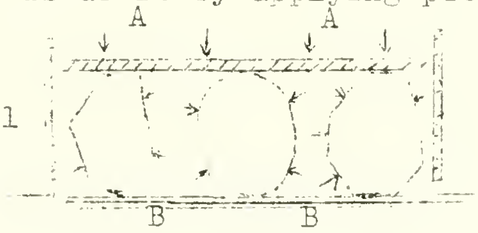
In general all rocks that are subjected to increased pressure will tend to act in the manner above suggested - to try to flow away from the directions of greatest pressure and to compact themselves by loss of water or by rearrangement of their grains or crystals so as to occupy in the aggregate decreased volume. The rearrangement of the crystals which was described in the case of the limestone above may be discussed a little more fully now.

All rocks - igneous or sedimentary - have some water associated with them even if it is only in the form of the thinnest of films surrounding each grain or crystal. The film in some cases may be increased in thickness and in some rocks the pores or interstices between the grains are all filled with water. In whatever form or amount it may be present it remains true that water is a constituent of practically all rocks in the earth's crust. A film of this water will surround each grain or crystal and will be in very intimate contact with it. Under such circumstances no mineral is absolutely insoluble although the degree of solubility is very, very slight. The solubility of the grain may, however, be increased in several ways. One of these is by the increase of temperature, another by the increase of pressure, and a third by the introduction or addition of some

other solvent to the film of water. Since in this part of the discussion we are dealing with the effects of pressure, we will consider the influence of pressure in changing the character of rocks by the solution of their minerals.

As an illustration let us consider the solution factors about a number of grains as illustrated in the diagram below. Let a number of grains be placed between two plates A and B and let the rest of the space between the plates be filled with some solvent which under normal conditions has dissolved as much of the substance of the grains as it can. The addition of any more of the substance then could only be brought about by one of the factors noted above. Let us employ the factor of pressure and let us do it by applying pressure upon the plates A and B. This

Fig. 1



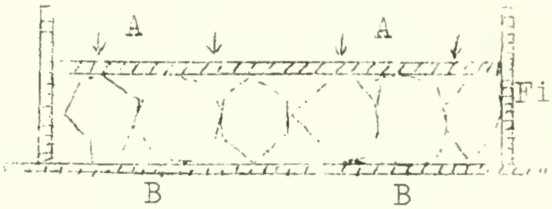


Fig. 2

pressure must be transmitted from A toward B through the grains between them and the pressure is applied at the points or faces in contact with A and B. Hence at those places the grains will tend to dissolve and the solution move away from the point or face of pressure. But when the stronger solution moves to the free side or face of the grain there is not enough pressure to keep it in solution and hence it will tend to precipitate it out or to form a film of solid material again which adds itself to one of the free faces, as indicated by the arrows which in the diagram are directed toward a few of the faces that will be receiving films of solid which are being pushed out of the solution which has become oversaturated on account of the extra pressure at the faces in contact with A and B causing an increased concentration at those places - which concentration could not be maintained elsewhere where the pressure was less.

If now in Figure 2, where the grains are all in contact with each other along the direction MN, pressure were again to be applied between A and B solution would go on as before and the precipitation which would ensue would take place on the free surfaces of the grains as illustrated. If the pressure and hence the solution and redeposition were to continue long enough the tops and bottoms of the grains would be dissolved away and the material would fill all the pores that existed between the grains. With the elimination of the pore space it is evident that the system is more compact now than before pressure was applied.

This was the principle that was largely effective in bringing about the consolidation of the limestone to Marble. Let us now apply it to a quite different rock - Sandstone. In the case of sandstone there is usually a fairly large amount of pore space. In some cases the application of pressure over a very long period of time may cause such a consolidation as suggested above, the silica of the quartz being dissolved from points and faces of grains which are pressing against one another along the direction of greatest thrust and being deposited in pores or along free faces of quartz which are directed toward points of less pressure.

In time the pores may be completely filled and the sandstone, which was originally made up of a number of grains of quartz rather loosely cemented together and with many pore spaces intervening, is now a consolidated mass of quartz with a very small amount of interstitial spaces. This rock consolidated to a fairly solid mass of quartz from sandstone is called QUARTZITE.

The above alterations of shale, limestone and sandstone under moderate conditions of metamorphism are normal modifications under conditions which may not be too intensive in their application to the rock mass. In the case of some of the shales the processes may be carried even farther than outlined above.

If the conditions of solution under pressure (or pressure and heat) are intensive and continued for a long time, it may happen that a crystal "A" on being dissolved will have its solution mixed with the solution from another crystal "B" of different kind and from this mixed solution there may be precipitated a crystal "C" of a kind different from either "A" or "B". It may further happen that the third crystal "C" has some characteristics which neither "A" nor "B" had but which render "C" more adaptable to the conditions of pressure or movement prevalent in the rock at the time of formation. Under these conditions it is probable that "A" and "B" will keep on dissolving and "C" will keep replacing them as far as is possible under the circumstances.

We have already noticed that the oxides which make up the greatest part of the earth's crust are as follows:

Al_2O_3 SiO_2
K_2O
Na_2O
CaO
MgO
FeO

These oxides we noted were, in the igneous rocks, combined to form quartz and the feldspar and ferromagnesian silicates. They can, however, when taken in different proportions and in different combinations, form other minerals with quite different characteristics of crystallization and so forth from the rock forming minerals that we studied some time ago. For instance a mineral called staurolite is composed of Silica, Alumina and Iron Oxides and a mineral Garnet may be formed from the oxides of Silica, Alumina, and Iron or Magnesia or Lime. Each of these minerals is quite heavy having a higher specific gravity than the average of the feldspars and ferromagnesians which might have been formed, in part at least, from another combination of the same oxides. It is evident that the oxides are very well compacted in these minerals (Staurolite and Garnet for examples) and that when a rock in which these oxides are present in the form of lighter minerals is placed under great pressure there will be a possibility of them reforming to make the more compact type of minerals.

This reorganization of the oxides of a rock to form as far as possible new minerals of greater density is a common feature of the metamorphism of rocks by the application of pressure.

Again the oxides might be able to recrystallize in the form of micas or other minerals of similar habits of growth. Minerals of this type tend to develop platy or fibrous structure growing more readily in one or two directions than in the third. This habit of growth fits nicely into a system where pressure in one direction is greater than in the other two. In addition to the micas the minerals Chlorite, Talc, Hornblende, and Actinolite show this ability to grow freely in one plane or direction with

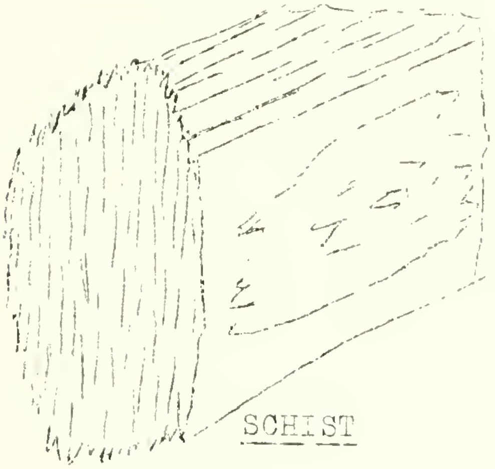
a lesser growth in the direction at right angles to the plane of greater growth. Chlorite is a platy mineral composed of the oxides Alumina, Magnesia, Iron, and Silica. Chlorite is usually formed when the basic minerals are being metamorphosed. Talc is composed of the oxides of Magnesia and Silica. Actinolite is a relative of Hornblende and has a needle or fibrous growth habit. Hornblende has already been referred to and is here mentioned again on account of its ability to extend its growth along one plane. All of these minerals would tend to grow mostly away from the direction of pressure, i.e. in a plane at right angles to the thrust and hence on account of their platy nature would tend to make the altered rock more easily fissile in planes at right angles to the thrust. This feature would therefore tend to accentuate the development of slaty cleavage induced by rock flowage, which is also, as we have already noted, at right angles to the direction of greatest thrust.

At the lower temperatures in the earth's crust the reorganization of the oxides to form new types of minerals does not take place so rapidly as it would at higher temperatures or over a longer time. If the rock is somewhat heated at the time of application of pressure or if there are present some liquids or gases which are particularly active in aiding solution and if the conditions are sustained over a long period of time then the effects of regrowth of crystals will be more pronounced, that is, more flakes of mica may be produced in the slate, for instance, and the flakes will be of larger size. Ultimately they may be large enough to be seen with the naked eye and we could speak of the slate as a mica slate. The slaty cleavage due to flow is still a dominant feature, but it is also marked by the presence of small mica flakes on the planes of parting. This type of slate is called a PHYLLITE.

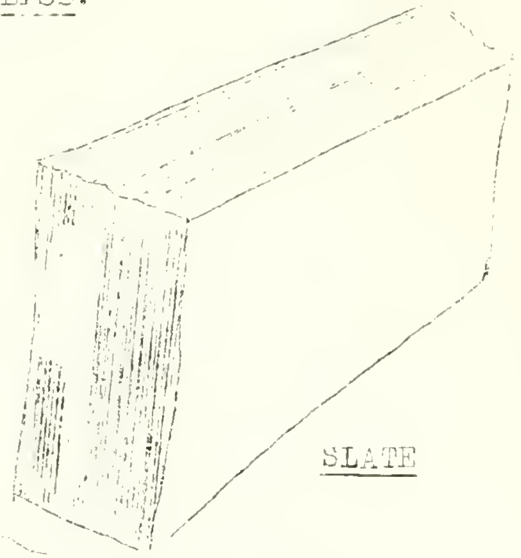
Under more severe conditions of alteration there may be developed two other types of metamorphic rock from the mud or clay sediments. In the original muds there may have been variations in the amounts of Alumina, Potash, Soda, Lime, Magnesia, Iron and Silica present. Depending partly upon this factor and largely upon the intensity of the alteration, we may have developed Schists or Gneisses instead of Slates or Phyllites. If the original muds were low in silica and the oxides required for felspathic mineral but higher in the more basic oxides then long continued and pronounced alteration will tend to develop the platy or fibrous minerals, Biotite, Chlorite, Hornblende or Actinolite. If these are sufficiently developed then the partings due to these minerals will be more important than the slaty cleavage. All of these minerals will lie in parallel planes which are at right angles to the direction of thrust but, since they are irregularly disposed, no one plane need be continuous for any distance and the partings will tend to jump from one plane to another parallel plane giving breaking surfaces which in general are parallel one another, but are somewhat irregular in any part of their course. This type of parting is called schistosity and the rock is called a SCHIST. Depending upon the characteristic mineral which causes the lines of parting the rock is called an ACTINOLITE SCHIST, HORNBLENDE SCHIST, CHLORITE SCHIST, TALC SCHIST, or BIOTITE SCHIST.

If the original muds were high in silica and the felspathic oxides then there were present the very materials which under proper conditions could make quartz and felspar. If the alteration factors are very strong, that is, the pressure is great and the temperature rather high, there will

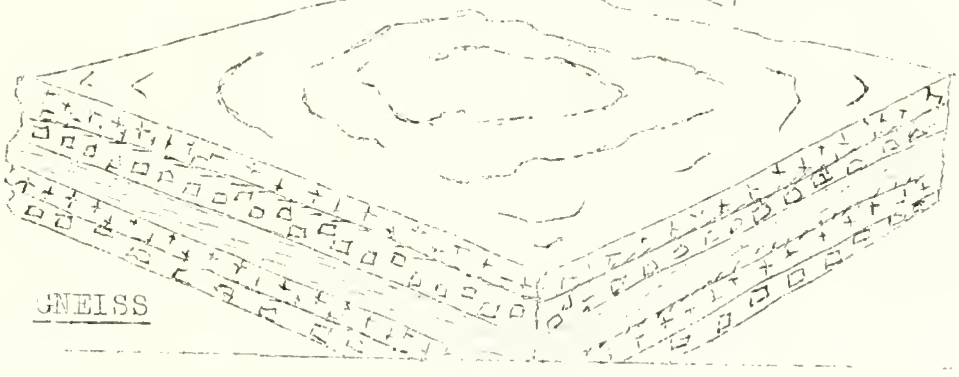
be an attempt to reorganize these oxides again into compact felspars and quartz with the ferromagnesian oxides becoming Hornblende or Biotite. These minerals it will be noticed are the minerals from which the original sandy muds were ultimately derived and now for the sake of compactness they are again built up. In the rebuilding, however, they are not arranged as in the granite but in more or less orderly layers or bands of quartz, felspar and hornblende or mica. In this arrangement of banding of like minerals together the whole mass probably takes up less space than if they were indiscriminately mixed with one another. On account of their shapes the felspars and quartz grains do not lend themselves to a prallel arrangement within the bands but the micas may attempt some disposition to parallelism among their own flakes. This type of rock with marked banding in layers of similar minerals is called GNEISS.



SCHIST



SLATE



GNEISS

To summarize the metamorphic rocks derived from the sediments, largely by pressure, with or without the aid of heat or solutions introduced from outside the original rock:

Sandstone may become	Quartzite
Shale may become	Slate, Phyllite, Schist or Gneiss
Limestone may become	Crystalline limestone or Marble.

In Conglomerate the sandy matrix may become a quartzite and the pebbles may be rolled or squeezed or sheared according to the relative strength of the various kinds of pebbles to the matrix.

There is another rock called greywacke which is sometimes classed as a metamorphic rock. This was originally a sandy mud which has become very much compacted. Its more sandy bands do in places become quartzite and its more muddy bands do become slates but the bedding and original structure are usually so well marked that it is doubtful if this rock should, without some reservation, be placed in the metamorphic group.

METAMORPHISM OF THE IGNEOUS ROCKS

The igneous rocks like the sedimentary rocks may, under similar changes in temperature and pressure, with or without the introduction of heat and solutions from the outside, suffer metamorphism in varying degrees and of different kinds according to the composition of the rock. Since the igneous rocks are more massive and less porous than the sedimentary rocks they do not always show such striking changes as metamorphism sometimes brings about in the sediments.

Granite, for instance, will tend to have its minerals rearranged in bands of quartz, orthoclase, and hornblende or mica. The bands may be variable in thickness, from a fraction of an inch to six inches and more. The segregation in bands may be imperfect but it is always more or less evident, the dark ferrômagnesian minerals helping to bring out the lamination of the rock. The feldspars and quartz grains do not lend themselves to parallel arrangement within the bands but the mica and the hornblende often show parallelism within their bands. Such a rock is called a GRANITE GNEISS.

It may be suggested that there might be difficulty in distinguishing between a Gneiss derived from a sandy muddy rock (the sedimentary gneiss before described) and a gneiss derived directly from a granite, and, in many instances it is difficult to determine the origin of the gneissic rock. On the other hand, although the main minerals of the two kinds of gneisses are the same and the arrangement may be identical, there may be in some cases some features which may suggest a sedimentary origin or otherwise. The muddy rock which gave rise to a sedimentary gneiss may have had in it some oxides in excess of the amount required for the reorganization of the typical granite minerals, quartz and felspar. These excess oxides may form accessory minerals whose presence is suggestive of the sedimentary origin of the gneiss. Garnet is one of this type of minerals. Now garnet may be present in granite and, hence, in the granite gneiss but when it appears in great abundance in the gneiss there is always a suggestion that the origin of this gneiss was sedimentary.

Just as Granite may form a Granite Gneiss, so also Syenite and Diorite having high feldspar content may form Syenite and Diorite Gneisses.

In all the gneisses feldspar will be an important constituent and the banding or lamination of like minerals will be a structural or textural feature. In the schists the feldspars may or may not be present but in any case feldspar is not the dominant mineral in determining the texture of the rock. In the schists this dominant position is held by such minerals as a chlorite, hornblende, actinolite, mica or talc. Under differential pressures or thrust these minerals readily orient themselves to adjust their flakes or planes so that they will be at right angles to

the direction of greatest thrust. This gives rise to the parallel grain arrangement so characteristic of the schistose textures.

The more basic rocks are lower in the feldspar content than the granite, syenite and the more acid of the diorites, and hence under this type of metamorphism cannot develop a large amount of that mineral. For this reason the metamorphosed basic rocks (the more basic diorites, the gabbros and their relatives) will not be likely to show the gneissic arrangement. The breaking down or alteration of the basic minerals tends to give rise to chlorite, hornblende and mica and hence the metamorphic rocks formed from the basic rocks will be high in the platy or fibrous minerals and low in the feldspars. This will give to these rocks the schistose texture rather than the gneissic.

The basic igneous rocks therefore on alteration are likely to give rise to the metamorphic rocks CHLORITE SCHIST, HORNBLENDE SCHIST, MICA SCHIST, ACTINOLITE SCHIST.

To summarize the effects of this type of metamorphism on igneous rocks:

The Acid Igneous Rocks are likely to produce Gneisses'
The Basic Igneous Rocks are likely to produce Schists.

In the precambrian of Canada there are present a great many rocks which were originally of the basic igneous type, either intrusivesor surface flows. In the alteration of these rocks the greenish chlorite gives to the rock a dark greenish cast of colour. On this account they are familiarly called Greenstones. They may or may not have the schistose texture developed, in fact the basic flows which have become greenstones most frequently preserve the old lava flow structures which their original movement first imposed on them. The alteration is an alteration of mineral content rather than textural readjustment.

The preceding discussion on metamorphism has dealt with the influence of pressure and largely of differential pressure in the work of modifying rocks, that is, it has been regional metamorphism that has been largely responsible for bringing about the alterations mentioned. In all these cases, however, and particularly in the case of the schists and gneisses, the addition of heat and outside solutions (when these are present) would be a very powerful factor in hastening or intensifying the effects being produced by pressure - the main agent of Regional Metamorphism.

CONTACT METAMORPHISM

We may now discuss briefly the effects produced by heat and solutions of intruding magmas on the rocks adjacent to them - Contact Metamorphism.

The alteration of the neighbouring rocks is usually marked by a distinct change in some or all of the minerals present in it. This change may be brought about either by the introduction of new substances from the solutions injected into the country rock from the magma or simply by a re-arrangement of the oxides already present so as to give new minerals [illegible]

In the metamorphism of the invaded rock there are two factors to be considered: (A) heat alone, or (B) heat plus a greater or less amount of hot permeating solutions.

Heat alone will tend to drive out some of the water contained in the neighbouring rock and will also tend to aid in the processes of solution which at all times are more or less active or at least potential in a rock which contains any amount of water. The effect of heat in most cases stimulates the solution of the oxides in the rock and hence increases the possibility of new arrangements to form new minerals. On slow cooling, subsequent to the invasion, the solution precipitates out the old or the new formed minerals and so the rock, after the invasion, may be found to contain new sets of minerals or merely to be more hardened and compacted than before. The latter effect will have been brought about by the driving out of some of the water and the reprecipitation of the old mineral types in the pores originally occupied by the water. In any case the effect will not be very widespread from the margin, or contact, of the invading rock and will in most cases be most marked within a few inches of the contact of the rocks with each other.

If the invading rock is accompanied by, or contains, large amounts of water or other gases the heating effect may be only secondary to the work done by the injection or infiltration of those gases into the country rock which has been invaded. The gases are able to penetrate far beyond the ordinary limits of the heating effect and to modify the rock in a gradually lessening degree as far as they penetrate.

The alteration due to the infiltration of the gases may be accomplished in two or three ways:

(1) The gases (or liquids) may merely stimulate the solution of the minerals already present. As a result of this increased concentration of solution the rock on cooling will likely have a more compact assemblage of the original minerals, that is, it will be a harder and more indurated rock. In addition there may be formed also some new minerals from the old materials.

(2) The fluids may dissolve and remove to another place some of the oxides already present and replace them by others which have been brought in with the solution from the magma.

(3) The solutions from the magma may, without much removal of the old minerals, precipitate new forms in the pores and interstices of the old rock.

In general the acid rocks are accompanied by larger amounts of penetrating gases or liquids than are the basic intrusives. Hence the basic intrusives tend to limit their effects to heating the adjacent rocks for short distances, driving out some of the contained water and stimulating solution of the contained minerals. On cooling and reprecipitation these minerals will tend to fill up some of the pores of the original rock and the resultant rock will be harder and firmer than before.

The acid rocks accompanied by penetrating gases which themselves carry much material in solution have usually a more profound effect on the

neighbouring rocks. Some of the materials in the solution, beside water or steam, are Carbon dioxide, Chlorine, Fluorine, Sulphur, Phosphorus and, of course, large amounts of silica and perhaps some of the felspar or other silicates. These substances may react with the oxides of the invaded rock to form new minerals or they may be precipitated in the country rock as they were carried in by the solution.

The effects on some of the invaded country rocks may be noted here:

Sandstone will likely have some or all of its interstices filled by silica precipitated from the solution forming Quartzite.

Shale, which has already been noted as containing a greater variety of minerals or oxides than the other sedimentary rocks, lends itself to the possibility of the formation of many new minerals as the result of the infiltration of magmatic juices. Some of these minerals are Andalusite, Staurolite, Garnet, Cyanite, Tourmaline, Rutile, Hornblende, and Felspar.

Near the intrusion the shale may have been baked or even partly melted by the intrusion, the outer zone of which itself may be modified by the inclusion in it of some amounts of the melted and digested shale. The hardened and baked slate near the contact is called Hornfels.

Limestone near the intrusion may have some of the Carbon dioxide driven from the calcite ($CaO:CO_2$) with the Calcium Oxide uniting with the Silica to form Calcium Silicate. The rest of the limestone will tend to be recrystallized to form Marble. Some of the minerals associated with the marble or limestone near the contact are: Wollastonite, Diopside, Biotite, Scapolite, Tourmaline, Garnet, Vesuvianite, Corundum. Some of these are due to minerals introduced with the injected solutions and some are due to small amounts of impurities in the limestone. Mud or shale is a common form of these impurities and the presence of the Alumina in small amounts in the mud gives rise to much of the aluminous content of the new formed minerals.

It is obvious that the minerals or elements which occur in the magma in the small amounts already noted in dealing with igneous rocks will probably be available in the juices which are ejected from the magma and penetrate the neighbouring rock. Among the minerals to be found in the contact zone, therefore, we might expect to find compounds containing some or all of the elements that were mentioned as being present in greater or smaller amounts in the magma. Some of these minerals are: Arsenopyrite, Axinite, Chlorite, Cyanite, Epidote, Fluorite, Magnetite, Molybdenite. Pyrite, Pyrrhotite, Rutile, Scapolite, Specular Hematite, Sillimanite.

The carbon dioxide of the magma may be given off both while the magma is molten and while it is solidifying and cooling. The migration of this gas into the neighbouring rock may extend one thousand feet or more and it may cause a change of the silicates to carbonates in the rock that it penetrates. This is especially noticeable in the neighbourhood of porphyries. The occurrence of carbonate rocks so often noticed in association with gold bearing areas is not always due, however, to the carbon dioxide derived from porphyries as there is evidence that the gold bearing solutions themselves carried large amounts of the gas which escaped from the vein channel into the adjacent rocks.

ORE DEPOSITS

In our discussion of geology up to this point we have been concerned mostly with the rocks of the earth's crust and the forces that act upon them. The rocks are made up of minerals which in turn are made up of alumina, potash, soda, lime, magnesia, iron and silica and - in the case of limestone - carbon dioxide. The number of elements in these oxides is nine in all, including oxygen, and these elements in the form of rock forming minerals make up about 98% of the material visible in the earth's crust. The other 2% is made up of the rest of the [illegible]4 elements, all of them in exceedingly small, and some of them in almost infinitely small proportions. Under the head of Ore Deposits we shall discuss the occurrence of some of these less common elements and the minerals which contain them.

From the time that his intelligence first enabled him to recognize the possibility of a stone as a weapon or tool, man has gradually been making more and more use of earth's materials as tools to increase his efficiency or as ornaments to please his fancy.

At first only the most readily available materials were utilized, but experience and communication taught him that some materials other than common stone could be better adapted to his purposes. The flaking of obsidian produced chips with very sharp edges which gave him an excellent cutting tool and the tougher flints made possible new types of tools and weapons which were much more effective than those fashioned from ordinar stone. The flints did not occur so widespread nor so abundantly as the common stone, but in certain areas they did occur scattered in chalk. [illegible] weathering of the softer chalk the harder flints were often accumulated [illegible] some numbers at the foot of a cliff or scattered over the surface of the ground. This segregation made the securing of the flints somewhat easier and taught the early collector the advantage of seeking for his collecting grounds those places where there was a natural concentration of the materials he desired.

Since then man has made more and more use of the 92 elements of the earth. Since altogether the elements other than those in the rock forming minerals make up only 2% of the earth's crust, it is evident that they must be very sparsely distributed. In seeking them, man's problem has been as it was with the flints - to find places in the earth's crust where nature had concentrated the materials to the extent that they could [illegible] readily be recovered. The natural concentrations of these minerals, particularly of the metallic materials, form what we call Ore Deposits. There are, of course, varying degrees of concentration and the term Ore Deposit is usually restricted to those deposits in which the desired material has been sufficiently concentrated to make its extraction and recovery profitable under current economic conditions.

In the study of ore deposits, then, we will be concerned with [illegible] of the concentration and deposition of those minerals or elements that [illegible] has found desirable and wishes to extract from the earth. [illegible] the term ore deposits refers to the deposits of metallic minerals, or the minerals or ores from which metals may be obtained. In addition to these [illegible] deposits whose end products are non-metallic materials, such as talc, asbestos, limestone. To these is applied the term non-metallic deposits.

At this point we may summarize some of the conditions necessary for the concentration and accumulation of ores either from the molten magma or from the solidified rock.

(A) There is needed first a concentration of the ore minerals in the magma or the rock.

(B) There may be needed some opening or openings in the rock near the earth's crust where the concentrated minerals may be deposited. These openings, with their contained deposits, must be near enough to the present earth's surface that they may be discovered and worked at a profit.

(A) Concentration

There are at least two types of what we may call primary concentration:

(1) The concentration may have taken place in the rock while it was still molten and the concentrated minerals may have been retained in close association with the magma when it solidified, or it may have been ejected into other openings while it (the concentration) was still in solution. This may have been before or after the main mass of the rock magma had solidified.

(2) Concentration at the surface of the earth may take place as a result of the weathering of the exposed rock. This concentration may take place as a result of the removal of the undesirable materials from the rock, thus leaving the desirable minerals more concentrated in the residual material left in place on the surface. On the other hand the desirable materials may be leached out and carried in solution out into the waters of lakes or seas where they may be precipitated in the form of fairly pure beds of valuable mineral deposits.

To each of the above types of concentration there is possible also a secondary concentration, that is, a later concentration of the first concentrates some time after the first ore bodies have been formed. In some cases the mineral deposits would not have been rich enough to form an ore body were it not for this secondary concentration long after the first mineral accumulation had been accomplished. This secondary concentration is usually brought about by solution or solution and redeposition, i.e. by leaching out of the undesirable materials from the mineral accumulation leaving the deposit richer in the wanted minerals, or by solution of the wanted minerals from one place and redeposition of them in another place where, by this means, their percentage in the mass is increased to the point where the accumulation may be rich enough to form a workable ore deposit.

(B) Formation of openings to receive the concentrations of minerals.

If the concentrations are formed within the body of the magma, they may be ejected into the surrounding rock. Usually the escape is by some rock fracture through which it may flow into whatever openings may be available. The formation and character of these openings will be discussed later.

In the section on Igneous Rocks it has already been pointed out that the igneous rocks or their magmas contain, in addition to the rock forming minerals, a great many other elements in minor proportions. Within the magmas, in fact, may be found practically all the metals that man needs or wants. In the ordinary rock, or indeed in the ordinary magma, the amounts of these minerals is so small that it would be only at an excessive cost that the mineral could be extracted from the rock. The only hope that there is of recovering the metallics from the rock is that there may have been some concentration of the minor or rarer elements within the magma. It is fortunate that in many cases there has been such a concentration. One type of concentration has already been discussed under the heading of Freezing of Magmas. Mention was made specifically of the segregation of such substances as the minerals of Tin, Tungsten, Molybdenum, etc., in the very fluid solutions residual in the freezing magma, and it was noted that these solutions may have been expressed from the body of the magma and injected into Pegmatite dikes. It may further be recalled that it was pointed out that the segregation of the minerals into this pegmatite fluid was the first stage of natural concentration. When the fluid was injected into the dike there may have been selective zones, determined by conditions of temperature and pressure, where some of the metallic minerals were precipitated, thus giving the second concentration - a concentration of the first concentrate within the dike. Where this concentrate is sufficiently rich to be mined at a profit, we have a pegmatitic ore body of Tin, Tungsten, Molybdenum and so forth.

The concentration of the minerals associated with the pegmatite solutions will serve as an example of some of the segregations within the magmas. It is probable that in many cases the concentration is not as simple and as direct as was described for the pegmatites. It may be that there is first a differentiation of the silicates of the magma into two or more silicate portions and that one portion of the silicate may carry with it most of the metals. Further, it may even be that from this segregated portion there is a secondary segregation into two or more portions and that most of the fluid solutions containing the metallics are associated with one or the other of these portions. From this last segregation the aqueous solution may finally separate and in it will be contained the magmatic juices with a concentration of the metallic minerals.

It is possible, also, that, even as the magma was freezing, some of the magmatic juices escaped with their load of metallic minerals and seeped slowly from the side or lower part of the solidifying magma and crept upward along the contact between the upper solidified magma and the country rock, there to deposit some of the metallic minerals. This type of occurrence may be called a CONTACT DEPOSIT.

In dealing with the formation of the rocks, it was pointed out that there were several of the metallic elements which joined with the oxygen to form the rock forming minerals and that the rest of the elements were disseminated in very minute amounts through the magma. One of the most common of these elements is sulphur, and it tends to unite with many of the less common elements to form sulphides, even as the rock forming elements unite with oxygen to form oxides. The sulphides, as the mass cools, tend to associate themselves with the aqueous part of the magma, rather than with the silicate part.

In some cases the sulphide association of metals within the magma may be very large - so large, in fact, as to form what is practically a rock mass of its own, separated from, but associated with, the silicate or ordinary rock mass forming the rest of the magma. In this large sulphide mass, which has segregated from the rest of the magma, the role of water is perhaps less important than in the pegmatite and similar concentrations. This segregation may form of itself an ore body, generally of very large size. The segregated mass of metallic sulphides may remain in close association with the rest of the magma, or it may be injected into dikes or other openings, just as would the silicate part of the rock magma. These large masses of ores so formed are known as magmatic segregations. It is evident that even the magmatic juices carrying the minerals are also magmatic segregations, but in common use the term generally implies a segregation of the magma into two or more portions of relatively large size, and in which water does not have the important part that it has in the pegmatitic type of concentration.

The copper nickel deposits of Sudbury have been placed in this class of magmatic segregation. The metals are iron, copper and nickel, which have united with sulphur to form combined sulphides of the three metals. It is a moot question whether the segregation took place where the associated rocks and ore now stand, or whether the metallic sulphides separated out elsewhere and were injected later into the contact regions where they are now found.

Another example of magmatic segregation occurs in northern Sweden at Kiruna. Here, there is an exceptionally large mass of iron ore in the form of magnetite (oxide of iron). In place this does not show any graded differentiation from any of the adjacent rocks, but appears to be in the form of a dike. The magnetite in the dike must have been injected from below and the relationships of the magnetite with the other igneous rocks in the neighbourhood strongly suggest that they were all differentiated from the same magma and migrated upward into their present positions in a series of successive events, that is, the magnetite, by magmatic differentiation, is a derivative from a magma which was probably a common parent to both the magnetite and the porphyries with which it is associated.

In the preceding paragraphs we have noted the possibility of several types of concentration of metals or metallic minerals from the molten magma of the igneous rocks. Summarizing these, we have:

(1) The fairly simple and direct concentration of magmatic juices with their contained minerals within the body of the magma, as exemplified by the solutions which are later ejected through and into the pegmatite dikes.

(2) The less segregated concentrations of the magmatic juices, which escape, probably by seepage, from the boundaries of the magma, and may creep up along the contact of the invading rock with the country rock.

(3) Segregation through magmatic differentiation in which the magma differentiates through several phases, and in which the metallic minerals are carried through to the end of the differentiation processes with one of the silicate segregations. From this final segregation the magmatic juice and its content are at last separated to escape as opportunity offers. e.g. A granite may send off a syenite differentiate and this may segregate into lamprophyre and porphyry. The ore bearing solutions may be associated with the porphyry.

(4) Segregation through magmatic differentiation in which one of the differentiates is itself composed almost entirely of the desirable minerals - with a relatively small proportion of associated water or other gases, that is, it is itself an ore. This differentiate may now occupy the position where it first settled on separation from the rest of the magma, or it may have migrated to some other position.

In the two pages preceding we have been discussing the processes of concentration of metallic minerals from the molten igneous rock. We may now consider the formation of some of the openings into which these concentrated solutions may migrate and in which they may deposit some of their load of minerals.

The form of the opening is probably a matter of indifference to the solutions, so long as it is accessible to them and provided it will remain open to permit free circulation of the fluid. Some forms of openings are discussed below:

(a) The opening may have been original in the rock. Of this type are the small bubble holes in lava flows, the pores in sandstone, or the interstices in a conglomerate rock. In such openings as these was deposited much of the copper of the Keweenaw copper region of Michigan.

In a somewhat similar class are the bedding planes and laminae of sedimentary rocks and the partings of schists or gneisses. The name Bed Veins is sometimes given to those deposits which are laid down between the beds of sedimentary rock.

(b) The opening may have been developed by solution previous to the advent of the ore solution. In this class are caverns in limestone and also enlarged bedding and joint planes in the same type of rock and due to the same cause.

(c) Openings may be developed structurally in association with the features of folding and faulting.

Toward the apex of an anticline the arch of each bed is being pushed up from below by the general thrust of folding. This tends to lift it away from the bed below it (at the top of the arch) and in many cases actual open spaces are developed between the beds at the top of the anticline. Furthermore, the outside or upper face of each bed is under tension and as a result of this tension, cracks may be developed in the upper surfaces of the beds in the anticline.

Of course these openings are only developed when the beds are strong enough to transmit the thrust from the syncline to the apex without yielding, i.e. they are strong enough to bear their own weight. In addition there must be no intervening soft beds which could be squeezed from the flanks of the anticline into the openings at the top, thus closing them against the ore solutions.

These deposits, formed at the top of an anticline, show in cross section some resemblance to a saddle, and for this reason are sometimes called saddle reef deposits. Deposits of this form are found in Nova Scotia and Australia.

Faults are developed when one block of rock in the earth's crust moves with respect to its neighbouring block (pp.16,17). If the fault surface (the surface along which movement takes place) were a perfect plane, there would be only a very narrow parting between the two blocks and this parting would be partly filled by fragments of the broken rock, either moderately large or perhaps ground to a fine powder. This material is called gouge. In the interstices of the gouge there may be sufficient openings to permit ore solutions to penetrate and perchance to deposit some ore minerals.

Most of the fault surfaces, however, are irregular so that after movement of either block of rock on the other the opposing faces of the two blocks will no longer fit neatly against one another. The protruding portions on the faces will tend to hold the two blocks apart so that larger and irregular openings result. Where two protrusions are in contact, the opening or cavity of the fault will be constricted, but where the recesses of the blocks are adjacent, the openings will be widened. This is illustrated in the diagrams below.

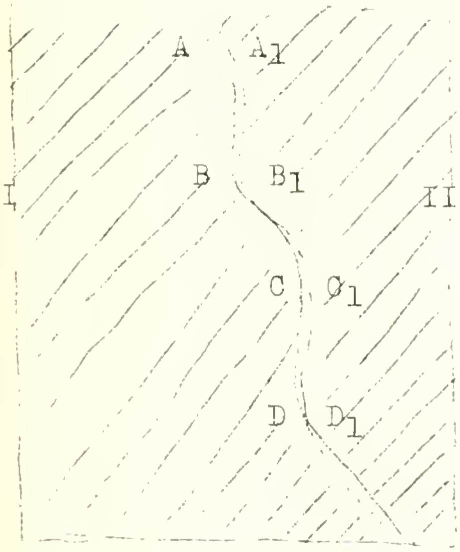


Fig. 1

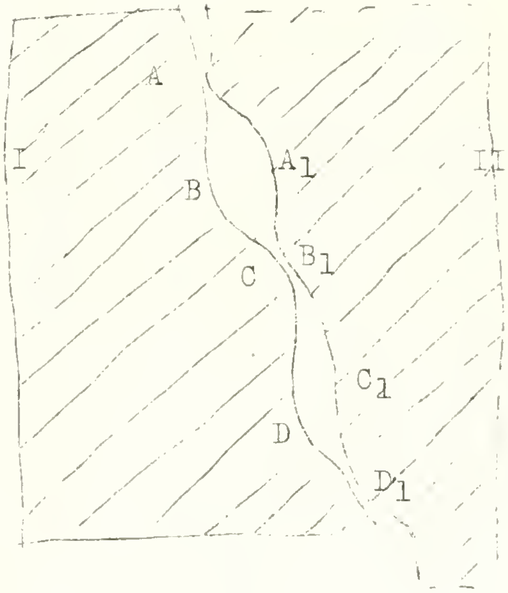
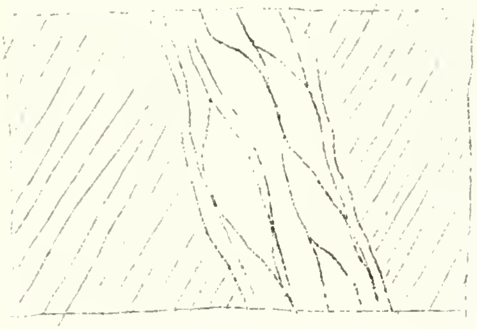


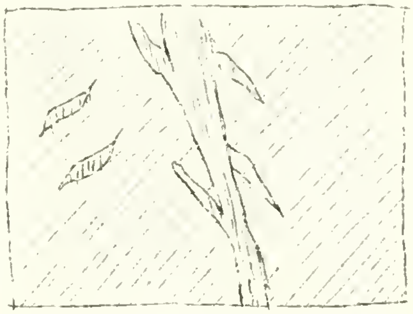
Fig. 2

In Figure 1 is shown the irregular fault surface before movement and in Figure 2 is shown the resulting relative positions of the adjacent fault block faces after Block II has moved down along the fault surface. As a result of the irregularity of the contact of the fault walls, the opening between them is irregular in its outline. If the opening is later filled with ore bearing solutions from which ore is deposited, it is obvious that the resulting ore deposit will swell and pinch along its course in both the vertical and horizontal directions.

In many cases the fault movement between the two adjacent blocks has not been along one surface, but has been distributed along many surfaces

forming a series of more or less parallel faults which may or may not have minor faults connecting them - the whole forming a very much broken zone of irregularly parallel and reticulating fault fractures. In this fault zone the shattering and displacement of the rock results in many openings which together offer the ore bearing solutions a wide zone for migration and penetration, with the probability of deposition of some of the valuable minerals from the solution.





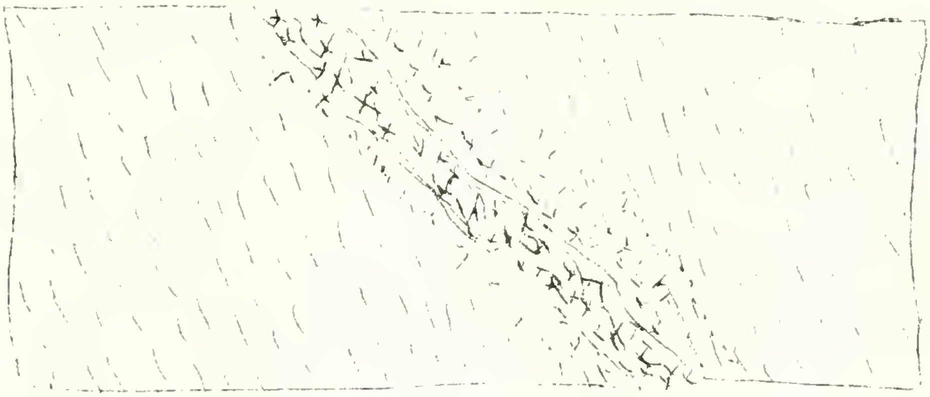
In addition to these major openings between the fault walls there may be developed minor associated openings either in the fault wall itself or within the rock some distance from, though adjacent to, the fault opening. The grinding of one block against the other may tend to tear open cracks in the face of the opposed block and the general thrust in both blocks may open tension or torsion cracks in the main body of the rock.

The fault fissure openings which we have just discussed differ from most of the openings previously described in that they usually have a tendency to the vertical direction and may penetrate to great depth. In this way they may extend below to the places of the original ore concentrations and hence may serve as their own feeders. In most of the other openings the cavities where the ore was finally deposited were not continuous to the sources of the ore solution in depth.

In all of the above discussion of openings the assumption has been that the openings into which the ore solutions were injected were of the present shape of the ore body, and that the solutions merely flowed into and through the cavities depositing their minerals in the cavities until the openings were filled or until the solutions stopped flowing. No great enlargements of the openings have been effected by the corrosive action of the ore solutions and there may have been little or no modification of the wall rock of the ore deposit.

There are many cases, however, where the first opening was not as large as the present ore body, in fact it may have been represented only by a minor fissure or channel, or even only by an irregular line or lines of seepage into which the ore bearing solutions might penetrate and through which they might migrate. In the migration of the ore solution some of its corrosive solvents may dissolve the wall rock of the channel and so enlarge the original opening. In the enlarged opening the ore minerals may be deposited at this or a later stage of the injection. In other cases the rock is only partially dissolved since some of its minerals may be more resistant than others. The more soluble particles will be removed and in the openings thus made minerals from the ore solution may be deposited. In some cases it would appear that the rock mineral was first

removed as above and ore solution minerals deposited as above, but in other cases it is evident that the rock mineral was replaced particle by particle by a mineral from the ore solution, the removal of one being effected by the introduction of the other. The replacing minerals of the ore solution may be in themselves valuable or valueless. Where they are valuable and they occur in sufficient quantity they form an ore body. Since this kind of deposit occurs as a result of the replacement of the minerals of the original rock by the ore minerals it is sometimes spoken of as a "REPLACEMENT DEPOSIT". The amount of replacement will depend, in part, upon the distance of penetration of the ore solutions into the rock and this in turn will depend upon the texture of the rock. It is obvious that if the rock is porous or schistose there will be more extensive penetration than if it is compact, hence the porous and schistose rocks lend themselves more readily to the development of replacement deposits than do the more solid rocks. The degree of replacement will probably decrease gradually along the margins of the replacement zone so that there may be no sharp wall to the ore body whose outer limits will be determined by the position of the zone of lowest grade ore that can be profitably worked.



In the last few pages we have been discussing the concentration of ore bearing solutions from molten magmas and the deposition of the ore minerals of these solutions in different openings. We may now consider the second type of concentration - the concentration of weathered materials from rocks exposed at the earth's surface.

When rocks are weathered at the earth's surface they may be broken up into fragments of the original rock, and the fragments decomposed into other kinds of minerals. Some of these minerals are soluble and some insoluble in the surface waters. The soluble material will be carried away in solution by the running water into the rivers, lakes and seas. The insoluble material must be moved along bodily but in time even this solid, fragmental material will be washed out into the streams and ultimately to the quieter water of the lakes or seas. Here it will be deposited as a fragmental sediment (clastic sediment) and in its deposition will be assorted according to its size and weight.

The ability of moving water to transport solid bodies is dependent upon two things: (1) the size and weight of the solid particle; (2) the velocity of the water. It is evident that a large boulder will not be moved along as readily as a pebble and that a pebble cannot be moved as easily as a grain of sand, if these fragments are all of the same material.

If the fragments are of different materials the problem of transportation factors is a little more complicated since the relative weights of equal sized particles (specific gravity) as well as the relative sizes of the fragments must be considered. For instance, it would be much easier to move a pebble of ordinary stone than to move a pebble of lead of the same size. To put the matter in another form, a pebble of stone could be moved as easily as a much smaller fragment of lead and hence it follows that the large stone and the small grain of lead would be moved by the same velocity of water flow, and dropped later at the same time when the velocity is sufficiently decreased.

If we observe the character of the stones on the bed of a stream where there are some variations in the velocity of its flow we may notice that where the stream is very rapid all the smaller pebbles are swept away and only the larger stones left undisturbed. Where the velocity is lower the pebbles may be dropped but the finer material carried on still farther till it reaches a place where the flow is so gentle that even the sand and mud are dropped. Entangled with the pebbles there may be some sand and usually if we examine this sand we will find that it is a rather "heavy" sand, that is, it has a high specific gravity so that the transportation factor of the heavy sand is about the same as that of the "lighter" but larger pebbles. In observing the difference in size of the pebbles dropped (or carried) in different parts of the stream, it is rather striking to notice the great difference in transportation power which is effected by an apparently small difference in the velocity of the stream. In the faster parts of the stream the increased size of the transported pebbles seems to be much out of porportion to the increase in the velocity which was able to set them in motion. This difference in proportion (of sizes of pebbles moved to velocities moving them) is quite real and not merely apparent. Careful measurement shows that the doubling of the velocity of a stream will increase the size of the particles it can move by at least sixty times and that the trebling of the velocity will increase the transportation factor by more than 700 times.

If it should happen that along the course of a stream or in the area tributary to it there are gold bearing veins then ultimately by weathering and erosion the fragments of these veins will be carried into the stream. The fragments will likely consist largely of quartz and similar minerals with a very small amount of gold particles. Owing to the abrasive action of the gravel in the stream the quartz and gold fragments will likely be further broken up and ultimately most of the gold freed from its associated quartz. Both gold and quartz will be swept along with the gravel of the stream but since a particle of gold is very heavy for its volume a very slight decrease of velocity will cause even a small particle of gold to be stranded on the bottom. There it will be embedded with much larger gravel pebbles which, owing to their lower specific gravities have about the same transportation factor as the fine particles of much heavier gold. Thus the gold particles which were originally disseminated through the quartz of one or many scattered veins along the course of the stream or the territory tributary to it are now concentrated in the gravel of the stream bed. This type of concentration is called a "PLACER DEPOSIT". Gold with its unusually high specific gravity of 16 to 19 (as it occurs in veins) is the mineral which perhaps is usually thought of as a characteristic placer deposit, but platinum, tin stone and other placer deposits are also of high economic importance.

Although we have used stream action as an example of the sorting power of water with the consequent placer concentration, it does not follow that concentration by water action is limited to streams or rivers. Wherever water is in motion there is brought into play this sorting and segregating action. As an instance of this we may recall the action of waves in the sorting of gravel and sand along the sea shore (p.10). If, with the gravel or general detrital material along the shore line, there should be any appreciable amount of gold or other valuable mineral of high specific gravity, the same sorting action that segregates the gravel and the sand will tend to concentrate the gold or similar minerals in definite zones within the gravel or sand. Thus there may be developed shore line placers similar in effect to the stream placers developed by river or creek action.

In discussing the development of placer deposits we have been considering only the concentration of the fragmental products of the weathering of rock. Some of the dissolved material may also be concentrated in beds in lakes or oceans. One example of this has already been noticed - the formation of beds of limestone from line in solution in the ocean water (p.10). In this case the weathering (decomposition) of the rock formed Calcium Carbonate from the lime of the silicates in the original rocks, which carbonate was carried in solution into the sea where it was later precipitated in various ways to form limestone. From the other bases of the silicate minerals (potash, soda, magnesia, iron) there may be formed carbonates or other soluble compounds, which, like the lime carbonate, will be carried by the running water away from the weathering rock toward the lakes and seas. Some of these soluble compounds reach the sea and there may remain in solution in the sea water indefinitely (e.g. the common salt of the sea water). Some of the soluble salts, however, may be precipitated from the water before they reach the sea and some may be thrown down after they mingle with the sea water. If the precipitated material is useful and is sufficiently free from other substances, or impurities, it may form a bed of ore that is rich enough to be worked at a profit, i.e. it is an ore deposit. Iron ores, gypsum, and salt are some of the valuable substances that occur in deposits accumulated from materials precipitated from solution in fresh or sea water.

It is possible that at some time you may have observed a small spring of rather clear water issuing from the ground and flowing into a stagnant pool of dirty looking water. The bottom of the pool was probably covered with a reddish yellow slime and an irridescent film floated on the surface of the water. On a small scale this occurrence is a fairly good illustration of the process of concentration of iron by the weathering of surface rocks and the precipitation of the dissolved material in segregated masses in localized areas. The water passing through the ground carried with it some dissolved carbon dioxide. and with its aid was able to dissolve some of the iron in the ferromagnesian minerals of the sand, gravel or disintegrating rock. In solution the iron was carried through the ground till the water which carried it finally issued to the open air as a spring. Here the water appears pure and clear and as such pours into the pool near it. In the pool the oxygen of the air and the action of small plants serves to change the soluble iron compounds in the water into other iron compounds which are not soluble in the water. These insoluble compounds are precipitated to the bottom of the pool where they accumulate as a reddish yellow sludge.

On a much larger scale large areas of rocks rich in ferromagnesian minerals (basic rocks) may deliver to lakes or seas waters which carry a fairly high percentage of dissolved iron compounds. The action of oxygen and of bacteria or small plants will precipitate the iron to the bottom of the lake or sea where through many years a thick bed of iron deposit may accumulate. Later this bed of iron deposit may be covered by layers of mud which in time will be turned to shale. We will thus have a deposit of iron interbedded with other sedimentary units. The bed of iron is likely to be contaminated with mud and other sedimentary impurities which, in many cases, may so reduce the percentage of iron in the bed as to render it useless as an iron ore. In some cases even in these very impure deposits of iron there may, however, be a further concentration of some of the iron within the bed by the action of circulating ground waters. Such segregation of some of the iron into localized areas within the larger beds may bring the iron concentration up to the point where it becomes a workable deposit.

Excessive evaporation of the water in restricted or confined seas may serve to concentrate some of the dissolved salts of the sea water to the point where the water is saturated with them and any further evaporation will bring about a precipitation of these salts. In this way there have been formed extensive deposits of gypsum (calcium sulphate), common salt (sodium chloride) and associated salts such as some of the salts of potash and magnesia. Changing conditions of climate or modification of the tributary drainage system may later bring a deposition of mud in the same sea, which mud will overlie the deposits of gypsum or salt. Thus the beds of salt or gypsum will later be found interbedded with shale or other sedimentary rocks.

SECONDARY CONCENTRATION

Subsequent to its formation any ore deposit may be subjected to further alteration or rearrangement. This modification of the ore deposit may either remove some of the desirable minerals and so impoverish the deposit, or it may serve to remove some of the undesirable minerals and so increase the percentage of the desirable materials in the deposit. In other cases the ore minerals of the deposit may be removed from one place and concentrated at another. Such segregation of the ore in localized positions usually tends to make the ore deposit more easily worked and hence more valuable.

The metamorphic agents which we considered some time ago are sometimes important factors in changing the character of ore bodies, but for purposes of illustration we will discuss only the modifications brought about by weathering and the circulation of ground water in the upper portions of the ore body. As metamorphic agents we dismissed these factors rather briefly before (p.32) but as agents in the modification of the upper zones of ore bodies they are frequently so important that they deserve some consideration here.

The rain water which falls over most of the earth is either (a) evaporated from the surface soon after it falls, or (b) runs off directly in surface waters - brooks and rivers - or (c) sinks into the ground through which it slowly seeps and circulates until at last it emerges at a lower level to join the surface drainage on its way to the

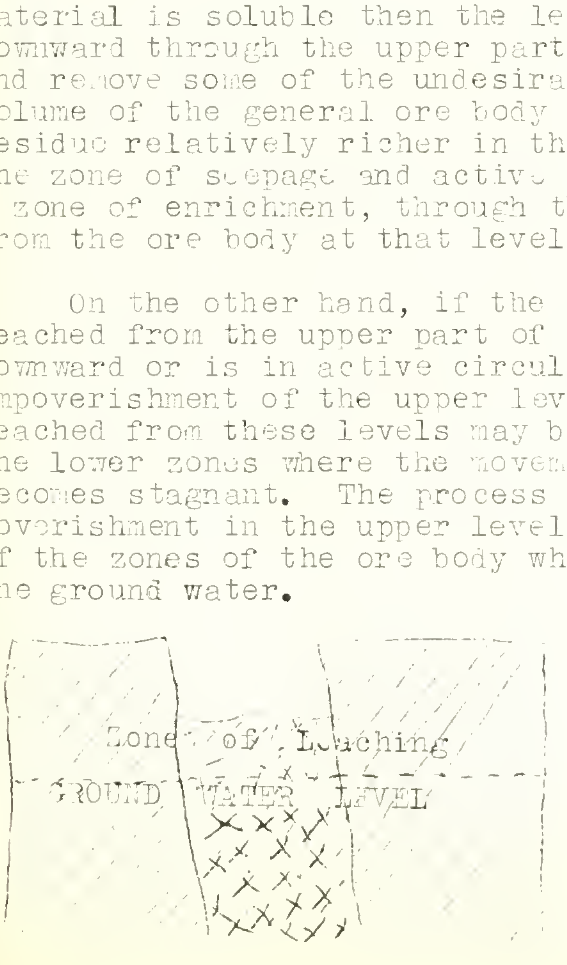
sea. This percolating water with the aid of other weathering agents is an effective factor in bringing about changes in the upper levels of ore bodies which reach the surface of the earth.

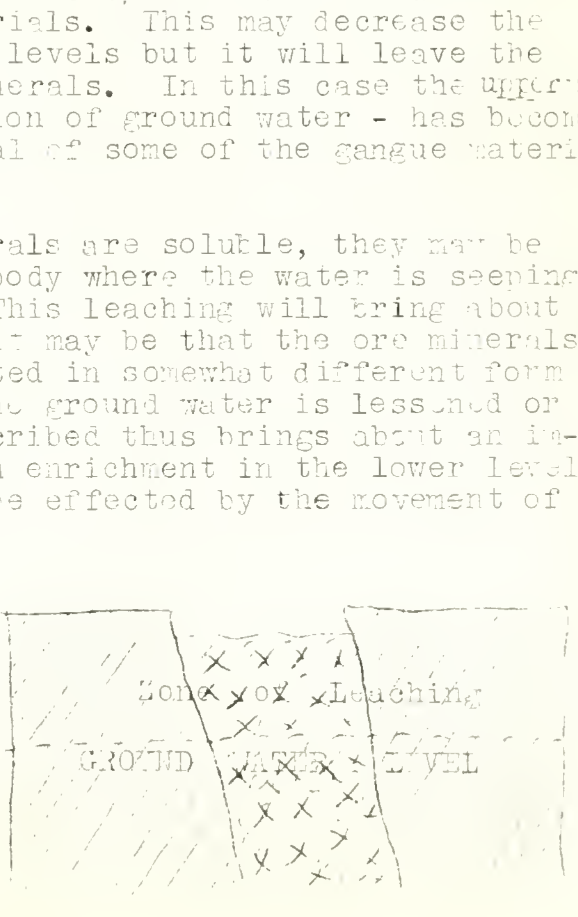
In the uppermost part of such an ore body is a section in which the materials of the ore body are merely dampened by the downward movement of the rain water. At a lower level and below it the ore deposit and the adjacent ground is water soaked. In the upper part of this saturated ground there is a fairly active circulation of the ground water which is escaping from these levels about as rapidly as it is descending from above. At lower and lower levels the movement of the water becomes slower and slower until at some depth it is practically stagnant. It is in the upper levels of dampened minerals and circulating waters that the modification of the ore deposit may be initiated while the final effects in depth are probably noticeable just below the levels where movement of the water has completely ceased.

The character of the modification of the upper part of the ore body - whether it is to be impoverished or enriched - will, of course, depend in part upon the solubility or insolubility of the minerals which form the desirable part of the ore body (called the ore minerals) and also the solubility or insolubility of the associated minerals or rock in the ore body which in that particular ore body are useless. (These useless associated minerals or rock particles are called Gangue.)

If the ore minerals are relatively insoluble and some of the gangue material is soluble then the leaching action of the ground water seeping downward through the upper part of the ore body will tend to dissolve and remove some of the undesirable materials. This may decrease the volume of the general ore body in these levels but it will leave the residue relatively richer in the ore minerals. In this case the upper zone - the zone of seepage and active circulation of ground water - has become a zone of enrichment, through the removal of some of the gangue material from the ore body at that level.

On the other hand, if the ore minerals are soluble, they may be leached from the upper part of the ore body where the water is seeping downward or is in active circulation. This leaching will bring about an impoverishment of the upper levels but it may be that the ore minerals leached from these levels may be deposited in somewhat different form in the lower zones where the movement of the ground water is lessened or becomes stagnant. The process just described thus brings about an impoverishment in the upper levels, but an enrichment in the lower levels of the zones of the ore body which may be effected by the movement of the ground water.





ORE DEPOSIT MINERALS

Very few of the metals of the ore deposits occur in the free or uncombined state. Just as the silicon, aluminium. potassium, etc., of the rock forming minerals were combined with oxygen to form oxide, so the elements of the ore deposit minerals tend to combine with oxygen or sulphur, or arsenic, or some other element to form oxides, sulphides, arsenides, or other compounds. In some cases the metals of the ore deposits may have combined with two of these, e.g. sulphur and arsenic, to form a sulphur-arsenic compound. This compound is called the Sulpharsenide of the metal.

Using iron as an example of a metal occurring in the free state or combined with one or more other elements we have the following possibilities:

Iron	free and uncombined is called		Native Iron
Iron combined with	Oxygen	forms	Iron Oxide
" " "	Sulphur	"	Iron Sulphide
" " "	Sulphur and Arsenic	"	Iron Sulpharsenide

A number of the metals occurring in ore deposits are listed below, and beside each is placed the symbol which, for convenience, we may use in further references to the metal and its compounds.

Aluminium	(Al)		Mercury	(Hg)	(Hydrargyrum=Quicksilver)
Antimony	(Sb)		Molybdenum	(Mo)	
Arsenic	(As)		Nickel	(Ni)	
Bismuth	(Bi)		Platinum	(Pt)	
Chromium	(Cr)		Tellurium	(Te)	
Cobalt	(Co)		Tin	(Sn)	(Stannum)
Copper	(Cu)	(Cuprum)	Tungsten	(W)	(Wolframium)
Gold	(Au)	(Aurum)	Uranium	(U)	
Iron	(Fe)	(Ferrum)	Vanadium	(V)	
Lead	(Pb)	(Plumbum)	Zinc	(Zn)	
Manganese	(Mn)				

As before mentioned, these elements may occur in the uncombined, or free, state, or in combination with one or more of the elements Oxygen, Sulphur, Arsenic, Antimony, Bismuth, or Tellurium, or one or two other elements.

For these substances we may use the symbols listed below:

Sulphur	(S)	Antimony	(Sb) (Stibium)
Oxygen	(O)	Tellurium	(Te)
Arsenic	(As)	Chlorine	(Cl)

In the tables below are shown some of the types of occurrence in which the metals may be found:

(A) Occurring in the free or uncombined state

(NATIVE)

Copper

Gold

Mercury

Platinum

Silver

Silver and Gold (Sometimes called Electrum)

Copper and Gold) Alloyed in
Copper, Silver and Gold) various proportions

(B) Occurring combined with one other element - Oxygen

Iron	(Fe)	with	Oxygen (O)	forms	Iron oxides	Fe_2O_3 Fe_3O_4	(Hematite) (Magnetite)
Iron and Chromium	(Cr)	"	"	form		$FeO.Cr_2O_3$	(Chromite)
Manganese	(Mn)	"	"	forms	Manganese oxide	MnO_2	(Pyrolusite)

Many of the metals may combine with Sulphur or Arsenic, of Antimony alone, or with Sulphur and one of the others mentioned. This set of combinations will be listed in the next table.

(C) Combining with Sulphur or Arsenic, or Antimony, or Tellurium, or with Sulphur and some other element

Copper	(Cu)	forms	Copper Sulphide	(Cu_2S)	- Chalcocite	
"		"	Copper Sulpharsenide	($Cu_3As_2S_7$)	- Tennantite	Grey Copper
"		"	Copper Sulphantimonide	($Cu_8Sb_2S_7$)	- Tetrahedrite	
Gold	(Au)	"	Gold Telluride	($AuTe_2$)	-Calaverite	
Iron	(Fe)	"	Iron Sulphide	(FeS_2)	- Pyrite or Marcasite	
"		"	Iron Sulphide	(Fe_6S_7)	- Pyrrhotite	
"		"	Iron Sulpharsenide	(FeAsS)	- Arsenopyrite or Mispickle	
Lead	(Pb)	"	Lead Sulphide	(PbS)	- Galena	
Mercury	(Hg)	"	Mercury Sulphide	(HgS)	- Cinnabar	
Nickel	(Ni)	"	Nickel Sulphide	(NiS)	- Millerite	
"		"	Nickel Arsenide	(NiAsS)	- Niccolite	
Silver	(Ag)	"	Silver Chloride	(AgCl)	- Cerargyrite-Horn Silver	
"		"	Silver Sulphide	(Ag_2S)	- Argentite	
"		"	Silver Sulphantimonide	(Ag_3SbS_3)	- Pyrargyrite	Ruby Silvers
"		"	Silver Sulpharsenide	(Ag_3AsS_3)	- Proustite	
Zinc		"	Zinc Sulphide	(ZnS)	- Sphalerite	

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Listed in the foregoing table are a few of the combinations of the metals with some of the other elements. In addition, we may have two or more of the metals combining with one or more of the other elements to form such compounds as:

Copper & Iron	with Sulphur	form	Copper Iron Sulphide	($CuFeS_2$)	- Chalcopyrite
			" " "	(Cu_3FeS_3)	- Bornite
Nickel & Iron	with Sulphur	form	Nickel Iron Sulphide	(NiFeS)	- Pentlandite

As noted before, (pp.54 and 55) some of the mineral compounds may be subjected to alteration in that part of the ore body exposed near the earth's surface where the ground waters carrying oxygen and carbon dioxide may attack the ores and change their composition. The reactions of oxygen, carbon dioxide and water, with one or two of the sulphide minerals, may be noted:

Pyrite (Iron Sulphide - FeS_2) is acted on by the oxygen in the ground water which tends to take some of the iron from the sulphide and to make an iron oxide, Fe_2O_3. This unites with some of the water to make a hydrated iron oxide called Limonite. In this compound two of the iron oxide groups take up three of water to form $2Fe_2O_3.3H_2O$. This compound is relatively insoluble and may remain as a capping on top of the leached part of an ore body below. It is brown or yellowish-brown in colour and is known to the prospector as Gossan, or Iron Hat. It is indicative of an iron mineral below and usually this iron mineral was originally a sulphide.

The Copper of the copper minerals will be sought out by the carbon dioxide of the surface water and together they will form a copper carbonate. Depending upon the amount of water which enters into the combination, the copper carbonate mineral will be Malachite or Azurite. The former has a beautiful green colour, the latter blue. These copper carbonates are also relatively insoluble and will remain at the surface of the weathered copper deposit to indicate by their presence the probable presence of other copper minerals at lower levels.

Having mentioned in the preceding pages a few of the minerals associated with ore deposits, we may now recast the tables to give a list of the ore minerals associated with different metals.

PRECIOUS METALS

Gold occurs Native (usually mixed or alloyed with Copper, Silver)

" " as Gold Telluride - Calaverite ($AuTe_2$)

(Gold occurs in veins, generally associated with the more acid rocks or in placer deposits)

Silver occurs Native (sometimes alloyed or mixed with Gold or Copper)

" " as Argentite - Silver Sulphide (Ag_2S)

" " as Proustite and Pyragyrite (Ruby Silvers)

(Silver occurs in veins, either native or associated with Galena or some other minerals (Cobalt), usually associated with basic or intermediate rocks)

Platinum occurs in veins or placers. Native, or as Sperrylite.
(Platinum is usually associated with the more basic rocks)

BASE METALS

The Metal:	Occurs as:		
Aluminium	Bauxite	$Al_2O_3.2H_2O$	- a residual product of weathering
	Cryolite	$3NaF.AlF_3$	- a fluoride of Aluminium and Sodium occurring in pegmatites
Copper	Native metal		
	Chalcopyrite	$CuFeS_2$	- Copper Sulphides
	Bornite	Cu_5FeS_4	
	Chalcocite	Cu_2S	
	Cuprite	Cu_2O	- Copper Oxide
	Azurite	$Cu_3(OH)_2(CO_3)_2$	- Copper Carbonates
	Malachite	$Cu_2(OH)_2CO_3$	

(Copper is usually associated with the basic or intermediate rocks. It occurs in veins or other openings.)

Chromium	Chromite	$FeO.Cr_2O_3$	- Iron and Chromium Oxides

(Chromium is usually associated with basic rocks.)

Cobalt	Smaltite	$CoAs_2$	- Cobalt Arsenide
	Cobaltite	$CoAsS$	- Cobalt Sulpharsenide
Iron	Hematite	Fe_2O_3	- Iron Oxides
	Magnetite	Fe_3O_4	
	Limonite (Bog Iron Ore)	$2Fe_2O_3.3H_2O$	- Hydrated Iron Oxide.

(Hematite and Magnetite may occur in veins, or the latter as a magmatic segregation. Bog Iron Ore occurs as sedimentary beds.)

Lead	Galena	PbS	- Lead Sulphide

(Note frequent occurrence of Silver or Zinc ores with Galena.)

Manganese	Pyrolusite	MnO_2	- Manganese Oxide.

The Metal :	Occurs as:		
Mercury	Native metal	- associated with Silver and Gold as amalgams.	
	Cinnabar	- HgS	- Mercury Sulphide
Molybdenum	Molybdenite	- MoS_2	- Molybdenum Sulphide
	(Occurring in Pegmatite dikes and veins in granite.)		
Nickel	Pentlandite	-(FeNi)S	- Sulphide of Iron and Nickel
	Garnierite	-	- Silicate of Nickel and other compounds
	(Nickel ores are usually associated with basic or ultrabasic rocks.)		
Tin	Cassiterite (Tin Stone)	- SnO_2	- Tin Oxide
	(Occurs in veins in granitic rocks and in Pegmatites, and as a placer deposit.)		
Tungsten	Wolframite	-	- Oxides of Tungsten, Iron and Manganese
	(Occurs in association with acid rocks in veins and Pegmatites.)		
Zinc	Sphalerite	- ZnS	- Zinc Sulphide
	Zincite	- ZnO	- Zinc Oxide

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GANGUE AND GANGUE MINERALS

By the term GANGUE we mean all that material in an ore body which is useless as a source of the desirable mineral of that ore body, but which, from its intimate association with the ore minerals, must be extracted with them. The gangue may include fragments of the country rock and/or minerals which were deposited by the ore solution. The most common of the latter is quartz, but in addition there may be Calcite, Siderite, and so forth. Sulphides also are common gangue minerals, but in some cases the sulphide may carry part of the values and hence becomes an ore mineral. It may also happen that a mineral which is part of the gangue in some ores may, under different circumstances, become valuable, and hence be sought as an ore.

HISTORICAL GEOLOGY

At the beginning of the course we noted the elements of which the earth is composed and considered the combinations of a few of these (eight) with one another to make what we called the rock forming minerals. We next considered the various associations of these minerals to form the different kinds of igneous rocks, - granite, syenite, diorite, gabbro, and their relatives. If our planet was originally a molten mass, then the original crust of the cooling earth must have been made of these rocks. Weathering and erosion broke down the original exposed rocks and transported the eroded material to the sea. Here the products of erosion were deposited as sediments, - conglomerate, sandstone, shale and limestone. Subsequent uplifts of some parts of the earth's crust and depressions of other parts may have exposed the sediments to erosion agencies and deposited their debris in oceans which, at that period, may have been covering areas that had formerly been dry land. With all this succession and alternation of exposure, weathering, erosion, and sedimentation, it is evident that in the long history of the earth there could be little chance of any of the original rocks of the earth's crust surviving to the present. It may be that in the depths of the ocean, or even at some places on the continent, there are still some remains of the original crust, but the present continental areas have been so worked over by the agents mentioned above that it is unlikely that any of the primordial crust there survives, or that it could be identified if it did so persist.

It is thus apparent that the earliest records of the earth's geological history have been destroyed or hidden with little hope that they may ever be found, and we must start our historical study with the oldest rocks we can find, leaving to conjecture the story of the earth previous to their formation.

In North America the oldest rocks known have their best exposures in the northern half of the continent - the most extensive distribution being in Northern Canada.

From the interpretation of these rocks, it would appear that physical conditions of the earliest geological periods were, in the main, much as they are now, and have been in the intervening ages. There were apparently continents and oceans and on the rocks of the continent the same, never ending agents of weathering and erosion were at work. Waters carried the continental debris down to the water covered areas where they were assorted and deposited on sea or lake floors, as gravels, sand, mud, and calcareous ooze. Volcanoes poured forth their lavas and intrusive rocks were injected into the beds already laid down. Such were the conditions obtaining when the oldest known rocks were being formed. We do not know the outlines of the continent, nor the limits of the seas, but since the rocks are assorted and stratified, we must infer great areas of water or seas and, for the provision of the debris to form the sediments, we must postulate exposed land areas or continents.

In Northern Ontario and Quebec there are many occurrences of these early rocks, but in the long long ages that have elapsed since they were formed, there have been so many periods of uplift and folding and of weathering and erosion that the greater part of them must have been worn away. They now appear in scattered patches which may or may not have been continuous with each other when they were first laid down. The

present lack of continuity makes the correlation of many of these isolated patches rather uncertain, but from their relationships to later rocks, we have been led to accept the correlations outlined in the following paragraphs.

In Quebec and Eastern Ontario, in the Ottawa Valley region, is a very thick deposit of limestone and dolomite with some muddy and siliceous beds. These sediments have since been altered to crystalline limestone, gneisses and quartzites, with crystalline limestone predominating. This series of rocks is thought to be the oldest of the area, and to it is given the name GRENVILLE SERIES.

In Western Ontario, to the north of Lake Superior, are deposits of sediments which were originally of a muddy nature, and which have now been altered to sedimentary gneisses and schists. To these gneisses and schists is given the name COUTCHICHING SERIES.

In Northern Quebec and Ontario, and in Western Ontario is a third series called the KEEWATIN. The Keewatin rocks are of two kinds - sedimentary and volcanic. The sediments are of two kinds: (1) muddy and sandy sediments which have been compacted and altered to form greywacke, quartzites, and slates (p.40); (2) banded iron formation, which consists of bands of iron minerals - magnetite, hematite or siderite (iron carbonate) interbedded with bands of more or less siliceous sediments. Some question exists as to the sedimentary origin of these interesting iron formations, but they are here included with the sedimentary group of the Keewatin.

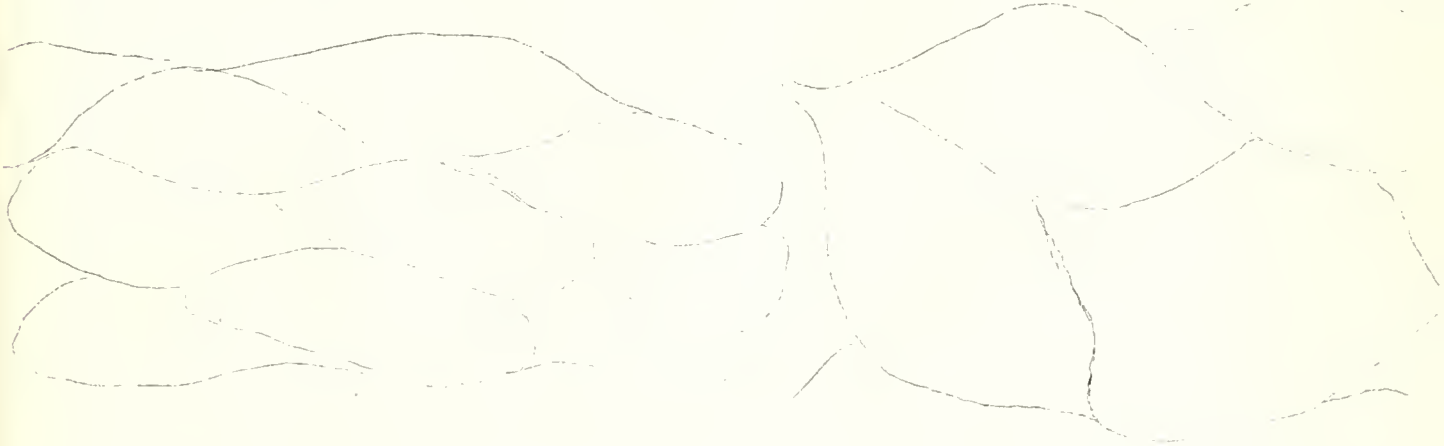
The Volcanics of the Keewatin are so extensive in their occurrence and make up so large a part of the series that they sometimes seem to entirely obscure the sedimentary part of this great succession of rocks. In composition the volcanic flows range from basic to acidic, but the basic types predominate. From the more acid eruptions there seem to have been given off from time to time vast quantities of volcanic dust to mingle with the other sediments as Tuff. Many of the flows seem to have been poured out into bodies of water while others may have come to rest on the land where weathering agents disintegrated and decomposed the rocks and the resulting debris was carried into the water to be laid down as the sediments previously described.

The volcanic flows, basic or acidic, have been subjected to much alteration since they were poured forth, and the determination of the original mineral composition is, in most cases, a difficult matter. However, the chloritic type of alteration, in most of the flows is fairly safe evidence that these flows were of basic rocks (p.41) and in other places the presence of a considerable percentage of sericite, together with residual quartz, is suggestive of the rhyolitic nature of the original flow.

In contrast to the marked alteration of the original mineral composition of the flows, is the (relatively) very excellent preservation of the grosser features of lava flow structures. The vesicular and amygdaloidal tops of the flows, the fragmental surfaces caused by the freezing, flowing and breaking of the cooling lava, and the flow lines of the moving, viscous liquid are still retained in a very high percentage of the flows.

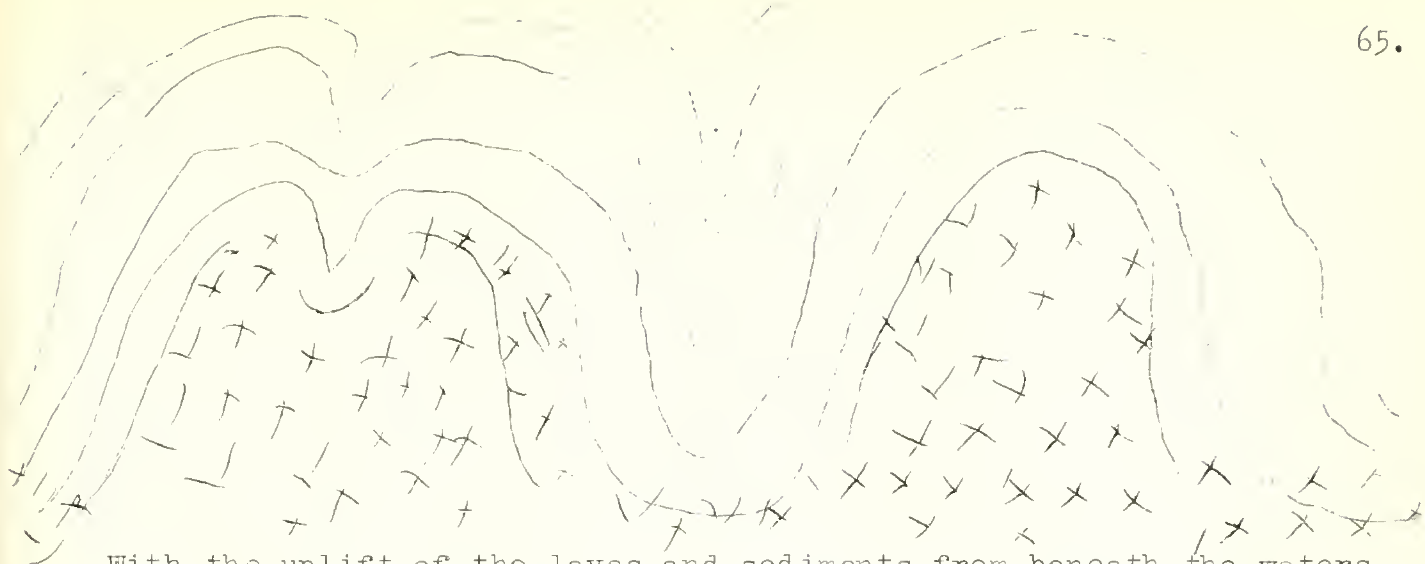
Most of the lava sheets have been tilted from their original horizontal positions by later earth movements, so that we now see on the surface of the earth horizontal sections which would have been vertical sections through the rocks as they were originally laid down. Due to the presence of the features just mentioned it is often quite possible to determine which was the upper and which was the lower surface of lava flow when it was first laid down, even though it may now be tilted on edge.

In addition to these features, there is one other type of structure common among the Keewatin lava flows - the pillow or ellipsoidal structure. In the pillow structure the appearance is as if a pile of pillows had been accumulated with sufficient weight on them to make them crowd into each other as much as possible - the pillows of an upper layer adjusting themselves alternately in position with the pillows of the layer beneath it. The ellipsoidal structure is a modification of the pillow with the pillows larger and more influenced by flow within the mass as the structure was being formed. The term "snowshoe lava" has also been rather aptly applied to this structure.



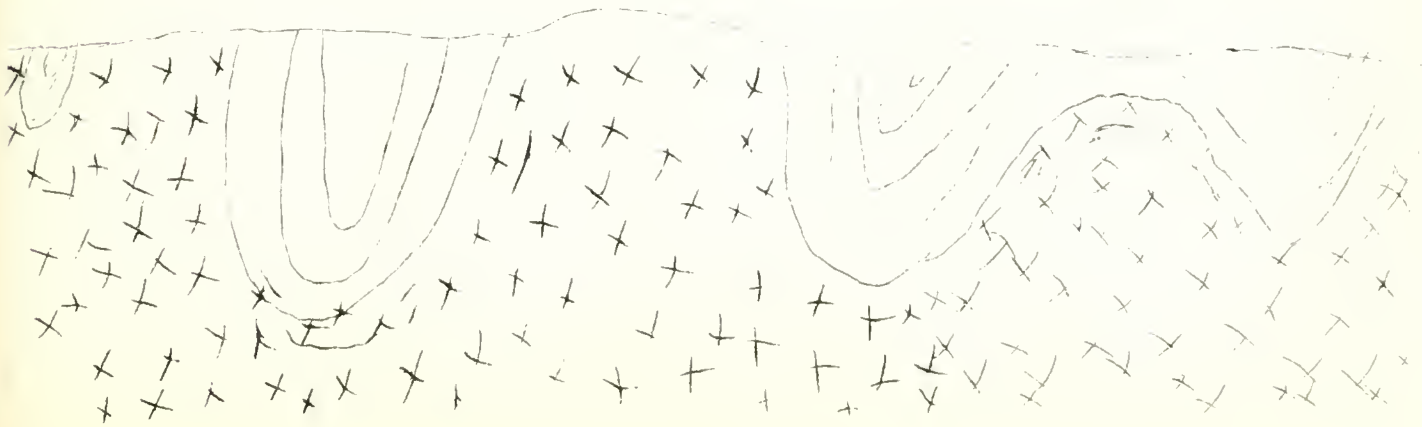
Since the original mineral composition of the rock has been changed so much, it is difficult, in the field, to give exact identification to most of these rocks. However, the presence of high percentages of chlorite in those volcanics that were originally basic gives to these dark coloured rocks a greenish cast which has given rise to the fairly useful, if non-committal name - GREENSTONE. So common are these types of rocks in the Keewatin, and so widespread, if not universal, is the use of the term greenstone, as applied to them, that in many minds the names Greenstone and Keewatin are almost synonymous terms.

During the latter part of the period in which these series of rocks (Grenville, Coutchiching, Keewatin) were being formed there were probably accumulating great stresses in that part of the earth's crust which is now covered by the northern half of North America. The stresses finally expressed themselves in strong thrusts along the northwest-southeast direction. In the adjustment of the crust to these thrusts many of the rocks were intensely folded and lifted out from the water in which they had been deposited. Accompanying the folding and uplift, and probably in part caused by it, there was a great intrusion of granitic rocks which probably migrated up into the arches of the folds, engulfing the lowermost beds and probably destroying completely the old floor on which these rocks had been laid down. This uplift and granitic invasion is called the Laurentian revolution.



With the uplift of the lavas and sediments from beneath the waters where they had been laid down, deposition ceased in those regions and weathering and erosion began to attack the newly exposed rocks. How long this period of destruction continued we do not know, but it was apparently of sufficient length to remove thousands of feet of hard rocks, and in doing this there was destroyed much of the historical record that had been written in their accumulation. At last the mountains of the Laurentian uplift were reduced to a flat or rolling plain and as an end to this phase of the earth's history, the worn down land surfaces sank beneath the sea, thus bringing to a close the first great cycle of geological history that we have recorded. This cycle includes the formation of the series of rocks first mentioned, their elevation above the sea, their subsequent erosion and destruction, and finally the subsidence of their remnants beneath the sea. We may record this cycle as below, with the oldest part of the cycle at the bottom of the column.

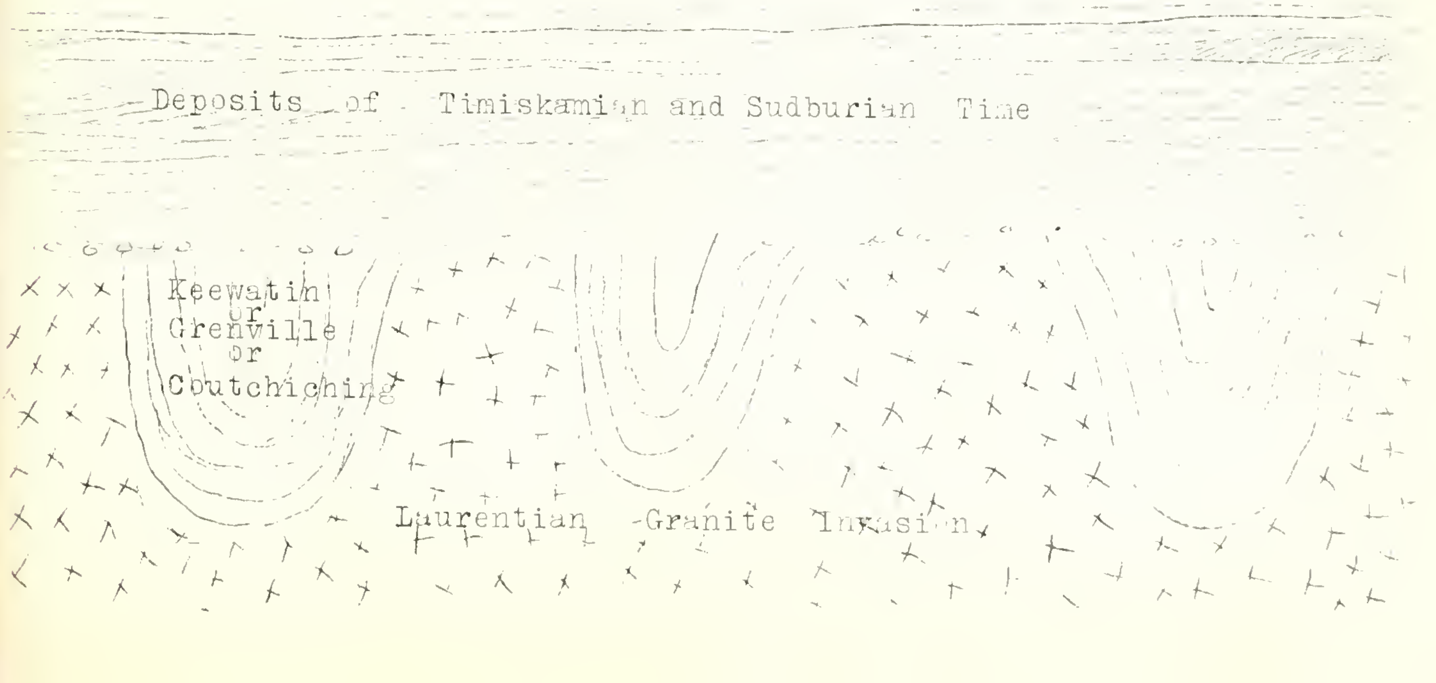
(Subsidence below the sea
(
(Erosion Interval (removal of much of the earlier rocks)
First Cycle (
(Laurentian revolution (uplift and intrusion of granites)
(
(Keewatin, Coutchiching, Grenville (deposition and accumulatio
(of rocks)



As the sea advanced over the sinking land areas there began to be deposited on the old eroded surfaces of the worn down Keewatin and Laurentian rocks a new series of sediments. These began with coarser types - conglomerates, sandstones, arkoses and muddy sandstones. (Arkose is a sandstone with a higher percentage of felspar fragments than is found in ordinary sandstone.) Continued sinking brought about also the deposition of some of the finer muds. Apparently volcanoes were active during this time also for, mixed with the sandy muds, we find fairly thick accumulations of volcanic dust - tuffaceous beds. Sometimes these are intermingled with the muds, and sometimes they form continuous and fairly pure accumulations of the tuff or volcanic dust. In places even the lava flows themselves may be found interbedded with the sands and muds of the normal sediments. To this series is applied the name TIMISKAMING (TIMISKAMIAN). These rocks are found quite widespread in Northern Ontario and Quebec.

In the Sudbury District is a series of rocks (the SUDBURY Series) which, from their relationships to the other rocks of the area, would seem to be of about the same age as the Timiskaming. Since the rocks of the Timiskaming Series are nowhere continuous with the rocks of the Sudbury Series, exact correlation is impossible and hence the two names are retained, one for each of the two series as described. The rocks of the Sudbury Series were apparently originally laid down as sandstones with a high quartz content, sandstones with a high felspar content, and sandy muds. These rocks have since been altered to quartzites, arkoses and greywackes - very similar rocks to those of the Timiskaming.

During the period of deposition of the Timiskamian and the Sudburian there was apparently very little crustal movement in the part of the world we have been considering. Toward the close of the Timiskamian - Sudburian time, however, the old thrust along Northwest-Southeast direction seemed to renew itself, and with much folding and faulting the rocks of these series were lifted out of the sea and elevated to positions where weathering and erosion could attack them.


Deposits of Timiskamian and Sudburian Time
Keewatin or Grenville or Coutchiching
Laurentian Granite Invasion

Accompanying the uplift of the Timiskamian and earlier rocks there was, as at the close of the Keewatin, an invasion of granitic rocks accompanied by much smaller amounts of complementary basic rocks. To this granitic invasion is given the name ALGOMAN and the same name may be applied to the uplift and revolution. The Algoman invasion would seem to have involved, or perpahs been caused by, an almost complete fusion of all the rocks underlying the old Keewatin-Timiskamian sequence, so that now it is very difficult to differentiate any of the old Laurentian granite from the Algoman granite which succeeded it at a much later time.

The Algoman granite reached the heights of its invasion under the larger anticlinal arches of the Keewatin-Timiskamian folds and there came to rest as huge, batholithic masses. Toward the flanks of the anticline - or down on the sides of the batholith -- there were, apparently, in some instances segregations of some of the silicates of the main mass, giving rise to syenitic, dioritic, and porphyritic or lamprophyre magmas. These differentiates at the flanks of the batholiths were thus adjacent to the synclinal members of the folds and, whenever faulting or fissuring occurred in the synclinal section, there was a possibility that some of these magmas might make their escape to inject themselves into the beds above. Thus it is that the syenite, diorite, lamprophyre and porphyry of the Algoman are so frequently to be found associated with the synclinal structures of the Timiskamian or Timiskamian and Keewatin.

As soon as the first sediments of the Timiskamian were lifted out of the water, the erosive forces must have begun to wear away the uprising rocks, and this erosion continued during their uplift and long after it had ceased. Owing to this contemporaneous uplift and erosion, the post-Timiskamian, or Algoman, mountains may have never reached the full height suggested, but the attitude of the remnants now observable would indicate for these Algoman mountains heights of many thousands of feet. By the post-Algoman erosion most of these mountains were cut down to a low plain almost at sea level, exposing much of the Algoman granite in the batholiths and leaving some remnants of the Timiskamian and Keewatin in the synclinal troughs and in other low or protected areas.

It is to be noted that so far as we know there was no land vegetation whatever during these early periods of the earth's history. There were no trees nor shrubs nor grasses - not even the lowliest mosses to clothe and protect the uplifted rocks from the agents of weathering and erosion. Under these circumstances disintegration and erosion must have been very active, but even with this active erosion a very long period of time must have been required to remove the thousands of feet of conglomerates, quartzites, greywackes and granites that were weathered and carried away during this period of exposure.

The Algoman granite is of particular interest in that it seems that with it is associated many of the gold occurrences of Ontario and Quebec. The more immediate association of the gold usually seems to be with the porphyry, diorite or syenite phases of the Algoman. Since, as already noted, these phases are more likely to be found in the neighbourhood of the synclinal sections the significance of synclinal structure to the prospector is evident. Furthermore, it is to be noted that the erosion of all the ages since the Timiskamian has removed most of the sediments

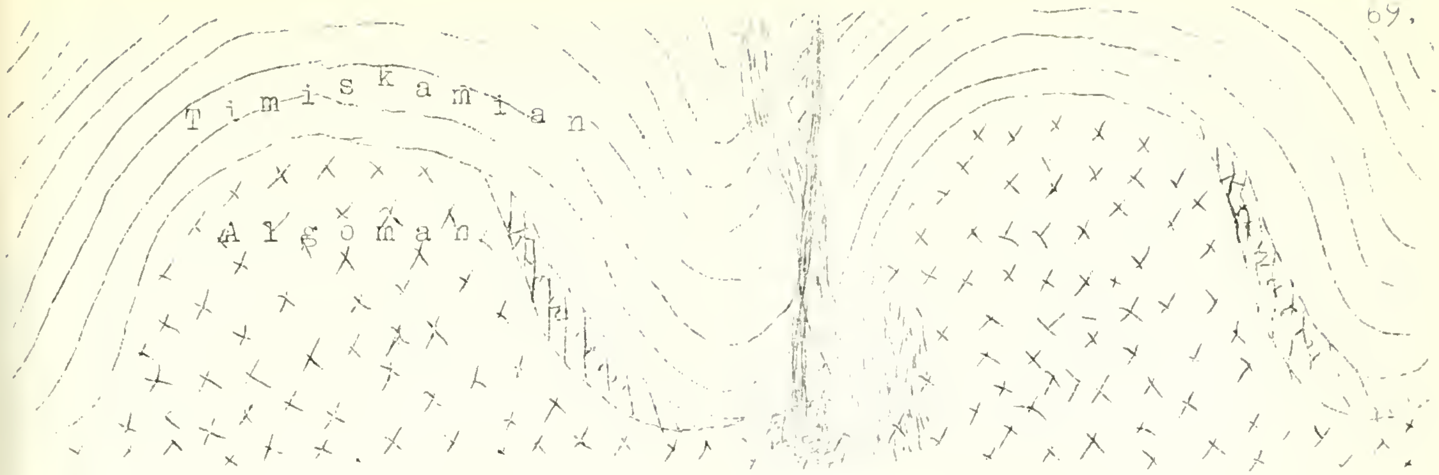
from the tops of the batholiths and has left in the synclinal basins some of the remnants of the Timiskamian and Keewatin rocks. Hence the long strips of sedimentary formation, flanked by granitic masses, are indicative of synclinal structures and these in turn are probable structures for the intrusions of the syenite, diorite, and porphyry segregates of the Algoman. As the gold of the Algoman is usually associated with the later phases of these segregates, it follows that the "sediments" (Timiskaming) or greenstone (Keewatin) areas are favourable exploratory grounds for the prospector.

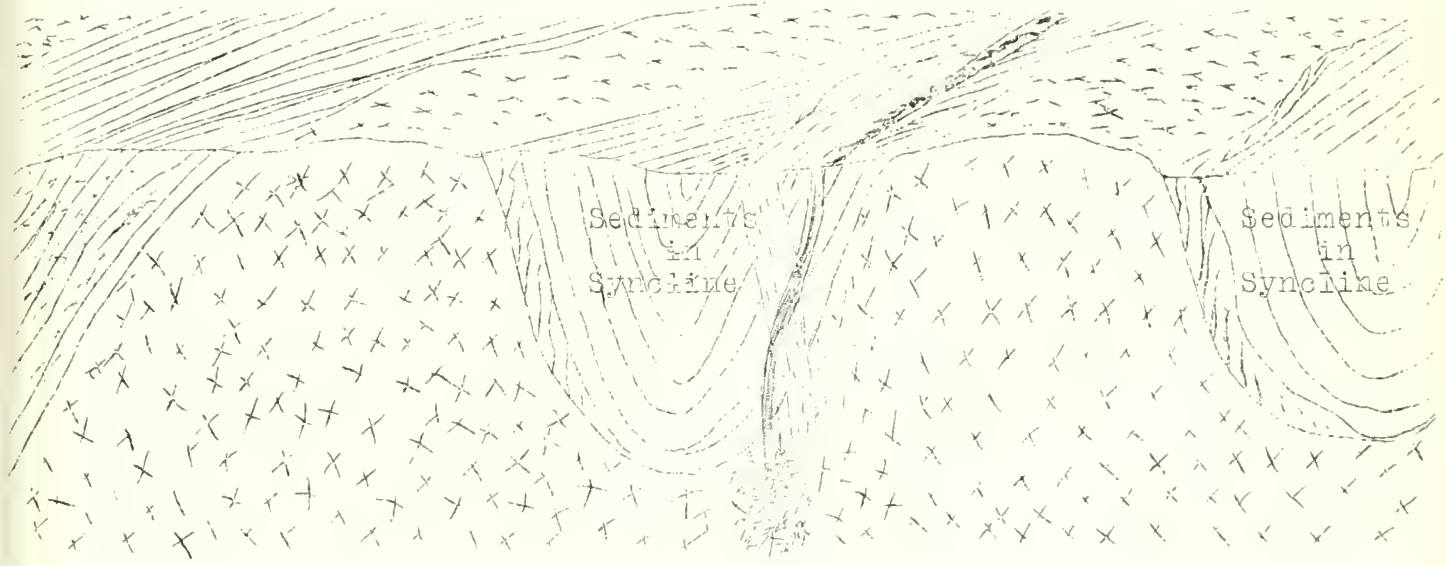
It is not to be inferred that the gold of the Algoman is never to be found in association with the granite or granodiorite bosses, but it is meant to be indicated that for the reasons given above the long strips of sediments or greenstones, or sediments and greenstones, flanked by Algoman granites, are favourable prospecting grounds.

Since the gold is assumed to be associated with the Algoman intrusives it is evident that gold of this age might be found in any of the rocks which were formed and in place before that time, but, since the Algoman invasion was completed by the end of the second cycle it is apparent that no Algoman gold is to be expected in any of the rocks formed after the close of this cycle.

Following the long erosion period of the post-Algoman revolution - probably one of the longest in the earth's history - the part of the earth which we have been describing sank again beneath the sea, thus concluding the second cycle of the early geological history of this part of the world. In the table below is summarized the sequence of rocks of the two cycles.

Second Cycle	Subsidence below sea level
	Post-Algoman interval of erosion
	Algoman Revolution (uplift and invasion of Algoman granites)
	Timiskamian-Sudburian (sedimentation with some volcanic activity)
	Subsidence below sea level
First Cycle	Post-Laurentian interval of erosion
	Laurentian Revolution (uplift and invasion of Laurentian granites)
	Keewatin - Coutchiching - Grenville (sedimentation and great igneous activity)





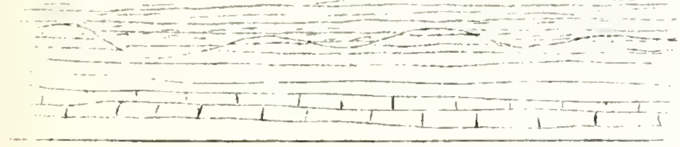
With the lowering of the land surfaces of post Algoman time and the subsidence of many of those land surfaces below the water, there began the third great period of deposition of sediments The earlier and lower sediments of this time were of the coarser kind - sandstones and conglomerates, to be succeeded later by muddy sands and even limestone in the deeper waters of the later part of this period. These rocks have since been somewhat altered and the sandstone now appears as quartzite and the sandy muds as greywacke. To this accumulation of rock is given the name BRUCE SERIES. After some period of subsidence and sedimentation an uplifting of the area and a retreat of the seas brought the submerged rocks to the surface and erosion began to destroy and remove the recently formed sediments. This uplift was not accompanied by the strong mountain building processes and granitic invasions that marked the Laurentian and Algoman uplifts, but it was sufficiently great to bring the Bruce sediments well above the waters in which they had been deposited. Following this period of uplift and erosion some of the areas were again depressed and the advancing sea began to deposit its sediments on the old eroded surfaces of the Bruce and earlier series. The sequence of deposition during this time was again much as it was in the formation of the Bruce Series. At the base were laid down coarser sediments, including conglomerates and sandy muds, passing up into sandstones near the top. To this group is given the name COBALT SERIES. The Bruce and Cobalt Series are

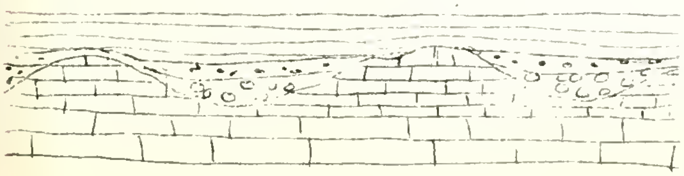
sometimes grouped under the name of HURONIAN - or, in some classifications the LOWER HURONIAN.

Following the Cobalt deposition once again an uplift caused a recession of the seas and the uplifted rocks were exposed to erosion. As at the close of the Bruce, no great folding or granitic invasion accompanied this revolution. After a period of erosion subsidence lowered many of the areas covered by the Bruce and Cobalt sufficiently for the sea to advance over them once more and to begin another period of deposition. To the sediments deposited this time is given the name ANIMIKEAN. In addition to the normal sediments of sandstone and shale - now altered to slate - are some deposits of tuff and coarser volcanic fragments - agglomerates. By some authors the Animikean is placed with what is called the UPPER HURONIAN.

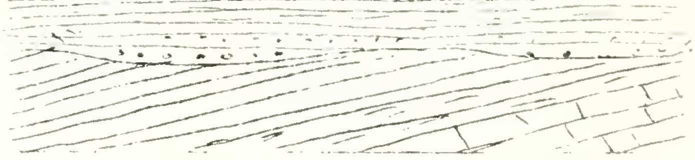
Post Animikean uplift disturbed the attitude of the bedding to some extent, and the recession of the waters allowed erosion to begin on the exposed sediments. On the eroded surface a new set of sediments was laid down. Owing to the tilting and erosion of the older beds these new sediments would not, of course, conform to the old bedding surfaces of the earlier rocks. The new beds were laid down horizontally on the truncated and eroded edges of the older formation, so that the separation of the older series and the newer series is well marked. Such a type of contact between two succeeding groups of rocks is spoken of as an unconformable contact and there is said to be an unconformity between the rocks involved When the unconformity is the result merely of an uplift and period of erosion between the two sets of beds it is called an erosion unconformity, since the contact between the sets of beds is along the old eroded surface of the lower set. When the older set of beds have been folded or tilted before being eroded, then there is a distinct difference in attitude between the lower beds and the new beds laid horizontally on top of the eroded edges of the older beds. This type of unconformity is called a structural unconformity. It is evident that a strongly marked erosion surface or high degree of tilting in the older beds is indicative of a long period of time between the deposition of the lower beds and the subsequent laying down of the beds above them. Thus, the degree of unconformity at a contact is a measure of the length of time that has elapsed between the formation of the two series of rocks involved, a great unconformity indicating a great lapse of time, and a minor unconformity suggesting a smaller lapse of time between the formation of the lower set of beds and the laying down of the beds above the unconformable contact.

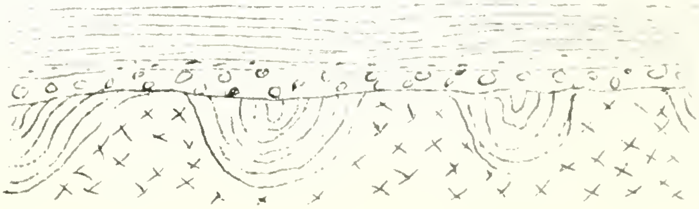
EROSIONAL UNCONFORMITIES





STRUCTURAL UNCONFORMITIES





It is evident that between the rocks of the first cycle and the rocks of the second cycle, and again, between the rocks of the second cycle and the rocks which overlay them, there must have been great unconformities. Between the rocks of the Bruce, the Cobalt, and the Animikie the unconformities are less pronounced. Beginning with the oldest rocks, as before, we may complete our table of rocks and of sequence of events to the close of the Animikean as follows:

(Upper Huronian) Animikie - sandstones, slates, tuffs, agglomerates
(Unconformity
(Lower Huronian) Cobalt
) Unconformity
) Bruce

GREAT UNCONFORMITY

Second Cycle) Algoman revolution - uplift and granitic intrusion
) Timiskamian-Sudburian

GREAT UNCONFORMITY

First Cycle) Laurentian revolution - uplift and granitic invasion
) Keewatin, Coutchiching, Grenville

. . . .

Following the uplift at the end of Animikean time this cycle was brought to a close by the usual erosion and subsidence to sea level.

The next series of rocks, called the KEWEENAWAN, is probably best seen in its full sequence in the Keweenawan district of Northern Michigan. Here the lowest part of the Keweenawan is marked by a thick series of coarse sediments - conglomerates and sandstones. These rocks were probabl laid down in shallow water, or, perhaps, on flat lying land surfaces. The same type of sedimentation is continued into the middle part of the Keweenawan, but the importance of the sediments in this middle part is overshadowed by the presence of great numbers of lava flows, piled up to enormous thicknesses. The volcanic activity was most marked at the beginning of the middle part, following which was a period in which sedimentation was again important, and a later period in which there was a slight recurrence of volcanic activity. In the upper Keweenawan there was again a period of heavy sedimentation with conglomerates and sandstones th dominant types. These rocks make up a total of many thousands of feet. A much smaller amount of shale was laid down between the conglomerates and

sandstones.

The igneous rocks of the Keweenawan include basic, intermediate, and acidic types, but in general, the basic rocks are much more important.

In the Keweenaw district the basic rocks appear as great lava flows and as intrusives into the underlying rocks. These intrusives are in the form of dikes, sheets, and laccoliths. In other areas - some far remote from the type locality - basic igneous rocks are fairly abundant as dikes, sills, and laccoliths. There may have been many volcanic extrusives also in these other areas, but if so denudation has removed them, so that now, the evidence of igneous activity is to be found mostly in the intrusive rocks invading all the earlier and lower series. So extensive is the distribution of these Keweenawan intrusives in Northern Canada that it is doubtful if there could be found many townships in Northern Ontario and Quebec that would not show in their geology one or more of these basic Keweenawan dikes.

The widespread occurrence of the basic igneous rocks of the Keweenawan and the amount of lava poured out and of intrusive rocks injected into the older series marks the Keweenawan vulcanism as the most profound migration of basic magmas since Keewatin time.

The basic rocks of this time are of unusual economic importance in that there is associated with them a large number of mineral occurrences over a range which probably extends from the Lake Superior district to the Arctic ocean. The economic importance of these rocks can well be appreciated when it is noted that associated with them are the following mineral deposits:

Keweenawan copper deposits

Sudbury copper-nickel deposits

Cobalt silver deposits and, probably,

Coppermine river copper deposits.

....

Following the laying down of the last of the sediments of the upper Keweenawan came an uplift of the continent and a retreat of the seas which exposed to erosion practically all of the North American continent as we now know it. The uplift of this great land mass, and the withdrawal of the seas, continued for many ages, and when, at last, the waters of the ocean began to wash over the northern part of the continent, a new era in the geological history of the world had already begun.

During all the long time of the first and second cycles and of the Huronian and Keweenawan periods there is little indication of any life in the ocean waters. Toward the latter stages of the Animikie and the Keweenawan there is some meagre evidence of the lowlier organisms, but their remains are too indefinite to be of much use in helping to classify the rocks in which they are found. With the invasion of the new sea following the Keweenawan retreat, there appeared in the waters an abundant and varied life. From now on, the rocks deposited by the waters of the

seas may be expected to contain some remnants of the plants and animals that lived in the oceans and these remnants - FOSSILS - are going to help us interpret the history of the earth. A new volume of this earth history may be begun and the first chapter may be labelled, for reasons noted later, as the Cambrian.

To all that great period which had passed away before the events of the Cambrian chapter began to be recorded is given the name PRECAMBRIAN, and so, in the summary of earth history to the close of the Keweenawan, we are using the term Precambrian to include all those series of rocks and sequences of events from the Keewatin and Coutchiching to the Keweenawan.

PRECAMBRIAN

	Keweenawan
	Unconformity
(Upper Huronian)	Animikie
	Unconformity
(Lower Huronian)	Cobalt
	Unconformity
	Bruce
	GREAT UNCONFORMITY
Second Cycle	Algoman revolution
	Timiskamian-Sudburian
	GREAT UNCONFORMITY
First Cycle	Laurentian revolution
	Keewatin, Coutchiching, Grenville

It was intimated in the closing paragraphs of Precambrian History that the presence of life in the post Keweenawan seas would enable us to record the history of the world in terms of the development of life. The life which first appeared in the post Keweenawan seas was varied and moderately abundant, but it was all of the invertebrate type. During the ages that followed the character of this invertebrate life slowly changed and as seas advanced on the land and receded from it again and again, in the ages to come, we find that the various types of invertebrate organisms are slowly becoming more specialized and better adapted to their environment. The progress of this development of life closely parallels the progress of the recession and advances of the seas.

We have noticed in the Precambrian eras that great periods were begun by the advance of the sea on the land and were brought to a close by the recession of the sea and the uplift of the land, leaving the older rocks and the rocks that had just been deposited exposed to the action of weathering and erosion agents. Thus, in Precambrian time the volumes and chapters of our history were marked almost solely by these physical events. In the time that follows from the close of the Keweenawan to the present the physical events will still serve as chronological markers, but within the rocks there is left an even better record of each of the periods of subsidence. The character of the life advances slowly at first, and for long periods none but invertebrate fossils are to be found imbedded in the sediments. Later, the primitive types of marine vertebrates - fishes - began to appear. These, in turn, gave rise to the amphibian group - a group which was beginning to learn to pass part of its life on the land. The amphibianswere the first of the vertebrate forms to pass any of their period of life on the land, but it would seem that as soon as the vertebrate group left the sea and made its habitat on the land, there began a very rapid evolution of one group of the vertebrates - the reptiles. These flourished for a long era, but in their turn yielded dominance to a still higher - the mammals. Based on the character of the dominant type of fossils, or life, the post Precambrian time is divided into three great eras - the Paleozoic, when marine invertebrates were the most common and dominant forms; the Mesozoic, when land vertebrates and land plants appeared, and the dominant vertebrate life was reptilian; the Cenozoic, when the development of vertebrate life reached its climax, and the mammals, which had begun their evolution in the last of the Mesozoic, assumed dominancy over all other forms. This Cenozoic age brings us up to practically the present position in geological history.

Before considering in more detail the cycles mentioned above, it might be well to note the physical features of the North American continent in those times.

From the Keweenawan on the outline of the continent was, in the main, much as it is now, with the exception that it was somewhat wider in extent on the eastern and western sides. In the major revolutionary periods of the Paleozoic, Mesozoic and Cenozoic the uplift of the continent was accompanied by mountain building processes and great and prolonged withdrawals of the seas. In the periods of subsidences of these cycles the seas invaded the continent but seldom completely covered it. It is probable that the floods in their invasions divided the continent into an archi-

pelago-like mass with the higher parts of the continents standing out as islands in the invading sea. During most of the time the Precambrian shield of Canada stood out as the bulwark of the continent, but from time to time it, too, was flooded in part.

On the western side of the continent, where the Rocky Mountains now stand, and on the eastern side, in the position of the Appalachians, were two long, broad, and rather shallow troughs or depressions. With the exception of short periods of emergence, sedimentation was going on almost continuously in these troughs, but continued subsidence kept the relative depth of the troughs fairly constant. It is evident that the subsidence of these troughs would bring about a down warping of the sediments already laid down in them, so that in form they have the structure of synclines. To such broad, gentle synclines is given the name *Geosynclines*. The main features of the continent during the Paleozoic era are: The Precambrian Shield to the north, the Rocky Mountain geosyncline on the west, and the Appalachian geosyncline on the east of the continent. To the north of the Gulf of Mexico the interior of the continent was low, and in each of the major inundations this area was flooded at about the same time as the geosynclines. At the height of an inundation the water of the interior sea might become confluent with the waters of the geosynclines and the waters of a sea invading from the Arctic to the north. During these times the continent became an archipelago, with one of the largest land masses extending eastward from the Appalachian geosyncline into what is now the Atlantic ocean. This now submerged land mass, which has been called Appalachia, was responsible for much of the continental debris which helped to form the sediments of the Appalachian geosyncline.

THE PALEOZOIC ERA

On the basis of the development of life and of the recessions and advances of the oceans on the land (diastrophisms) the Paleozoic era is subdivided into periods as follows:

Paleozoic Era	Permian	Late Paleozoic sub Era
	Pennsylvanian - Upper Carboniferous	
	Mississippian - Lower Carboniferous	
	Devonian period	
	Silurian period	Early Paleozoic sub Era
	Ordivician period	
	Cambrian period	

The rocks of the Paleozoic were first studied in England and Wales, and from English and Welsh associations they were given their names - Cambrian, from Cambria, the Latin name for Wales; Ordivician and Silurian, from the Ordovices and Silures, tribes of ancient Britons, inhabitants of

Wales and Devonian from Devonshire, England. The Carboniferous was given its name because of the great coal deposits which are included in it, and the Permian from the province of Perm in Russia. In North America the Carboniferous has been divided into the Mississippian and Pennsylvanian owing to the exceptional development of the rocks of the Lower and Upper Carboniferous in these areas. The Pennsylvanian is the period of the coal-bearing beds in North America. Except for some continental deposits, the Permian is not well developed in North America.

In North America in post Keweenawan time there were probably three great cycles of subsidence with deposition of sediments and revolutionary uplift followed by erosion with subsequent reduction to sea level. The first of these cycles may be considered as the Early Paleozoic, the second the Later Paleozoic and the third the period included in the Mesozoic and Cenozoic.

On each major invasion of the continent the seas advanced first into the troughs mentioned - the Rocky Mountain geosyncline and the Appalachian geosyncline,- and then into the great interior Mississippi area. From time to time floods from the north advanced until they met the floods from the south, and the whole continent, with the exception of a few islands, was covered during these periods of greatest inundations. During the latter part of the Early Paleozoic, parts of the Appalachian geosyncline began to be upraised, and finally, with the close of the Paleozoic, this trough was completely lifted out of the water and the rocks in it folded to make what is now the Appalachian mountain system. The Rocky Mountain geosyncline persisted through the whole of the Paleozoic and on into the Mesozoic. This we know, since rocks of that era are found in it. Towards the close of the Mesozoic the uplift of the continent on the western side involved great mountain building processes in the Rocky Mountain geosyncline, and by the beginning of the Tertiary the geosyncline was lost in the great uplift of the Rocky Mountains.

In the Early Paleozoic all the life of the world, both plant and animal was, so far as we know, restricted to the seas. The plant life was of the simplest type - unicellular plants and seaweeds. The animal life was of the invertebrate type and included such forms as corals, sponges, echinoderms (e.g. sea lilies), molluscs (snails, clams, etc.) arthropods (trilobites, eurypterids, etc.). In all of these groups there was a considerable advance from their appearance at the beginning of the Cambrian to their development as shown at the close of the Silurian. Some few indications of vertebrates are to be found in the form of what is probably a primitive fish in the Ordovician, with a further development in the Silurian, but the fish did not achieve any marked evolution until the Devonian of the Upper Paleozoic.

Following the revolution which marked the close of the Early Paleozoic a few plants had begun to live on land, probably at first along the damp shallows adjacent to tidal flats. In the sea the fundamental needs of the plant for food - carbon dioxide and water - were universally distributed in the medium in which it lived. When the plants began to live on land, however, the carbon dioxide had to be obtained from the air above and the water from the ground below. This meant that in order to get the water from the ground to the upper part of the plant where the carbon dioxide was obtained from the air, there must be developed some

type of conductive or vascular tissue which could carry the water from the root system to the upper green part of the plant. In this part of the plant, by the aid of sunlight the carbon dioxide and water could be elaborated into food for all of the plant tissues. To carry the manufactured food to other parts of the plant similar conductive tissues were also developed. By this type of development there was soon evolved in the land plants a system of a new type of cells forming what is known as a "vascular system".

This type of conductive tissue is characteristic of all the trees and higher orders of plants with which we are familiar today, but its first appearance was in some of the lower groups - the ferns, the club mosses and the horse tails (scouring rush). These plants began in the Devonian but did not reach their maximum development until the Carboniferous. In this period they occurred in the swamps and adjacent low lying lands in great profusion in tree-like forms reaching to heights of from thirty to one hundred feet. Those parts of the swamps that have been preserved in coal beds cover hundreds of thousands of square miles and widely distributed throughout them are the remains of these gigantic ferns, club mosses and horse tails.

To summarize the life conditions of the Paleozoic we may note; In the early Paleozoic sub era there were no land plants and in the sea there were only sea weeds and unicellular plants.

Since there were no land plants there could be no animal life apart from the oceans and other waters and the animal life is all marine or at least aquatic. The dominant forms were all invertebrate with the possible exception of a primitive fish-like form in the Ordovician and Silurian.

In the Devonian of the later Paleozoic sub era land plants began to appear and by the end of the Carboniferous had covered at least all the low lying ground with extensive forests of groups of plants classified as "Vascular Cryptogams" - the ferns, club mosses and horse tails. A plant "Cordaites" intermediate between the vascular cryptogams and the conifers appears in the late Carboniferous as does also a forerunner of the conifers themselves. The Cordaites plants like the ferns, etc., probably grew to a height of one hundred feet.

The aquatic invertebrate life of the early Paleozoic sub era continued into the late Paleozoic sub era with greater specialization in some groups and the disappearance of some members of other groups but with no really new forms appearing. The Devonian in some areas was marked by the growth of extensive coral reefs making up a great deal of the rock mass of some of the Devonian formations.

The marine invertebrates found their first great development in the Devonian with the evolution of the fishes making marked strides. The modern type of fish most common in present fresh or sea waters did not develop until later, but the plated ostracoderms, the primitive sharks and the shining scaled ganoids (relatives of the gar pike and sturgeon) abounded in the waters of the Devonian.

The foot print of an amphibian has been found in Devonian rocks and in Carboniferous and Permian times this group reached a high state of

development both in numbers and in the sizes of some of its representatives. The skeleton of one of these animals is fifteen feet long with an armor plated head four feet long.

ECONOMIC PRODUCTS OF THE PALEOZOIC ROCKS

The economic products of the Paleozoic are mainly those of the non metallic group.

Rocks for cement making or building stone or shale for brick making are obtained from some of the formations of all the periods mentioned. If the stone is of indifferent quality it may be used only locally, but in some cases the rock has certain exceptional features which warrant shipment to points some distance from the place of its occurrence. Thus the Garson-Tyndall stone of the Ordovician of Manitoba is used at points as far east as Toronto and Ottawa and the Indiana limestone from the Mississippian of Indiana is shipped to many distant points in the United States and Canada.

Oil and natural gas of fine quality occur in the Devonian in great quantities and are to be found in rocks of this age separated as widely as from Fort Norman on the MacKenzie river to the fields of Kentucky and Oklahoma. The Permian of parts of Texas, Kansas and Oklahoma also possess great reserves of these fuels. In smaller quantities oil and gas occur in the Ordovician and in still lesser quantities in localized areas in the rocks of all the other periods of the post Cambrian Paleozoic.

In rocks of the Silurian and Permian periods there are very important deposits of gypsum and salt.

Perhaps the most important economic product of the Paleozoic rocks in North America is the coal of the Pennsylvania period. The coal fields of this age in the United States and the eastern maritime provinces of Canada cover more than 200,000 square miles. Most of the coal is of the bituminous variety, but in the eastern United States there is a relatively small area of anthracite. The coal beds of the anthracite field were involved in the earth movements of the Appalachian mountain uplift and probably as a result of the heat generated in these processes the bituminous coals were altered to anthracites.

Smaller and unimportant deposits of coal are found also in rocks of the Mississippian and Permian periods.

Iron ore, which at one time was quite important, occurs in the Clinton formation of the Silurian, but of course the present great production of this ore in the Lake Superior region has reduced the significance of the Clinton ore at present.

Lead and zinc occur associated with rocks of Paleozoic age in the central United States and copper seems to have an intimate association with rocks of Carboniferous age in the states farther west, but the ultimate sources of these metals are probably to be found in igneous rocks of later periods.

THE MESOZOIC ERA

The Mesozoic era is divided into three periods - the Triassic, the Jurassic and the Cretaceous. These names were given by geologists in Europe in which continent the rocks of this era were first intensively studied.

The Triassic - the lowest system of rocks and the oldest period of the Mesozoic - is so called on account of the fact that it is readily subdivided into three epochs. The Jurassic receives its name because of its excellent exposures in the Jura mountains of France, Switzerland, and Germany. The Cretaceous was given its name on account of the thick chalk beds (Creta = Chalk) that occur in it. These beds form the famous chalk cliffs of England and the chalk of the adjacent area of Europe. The same names - Triassic, Jurassic and Cretaceous - are applied to the time periods and corresponding rock systems of the Mesozoic of North America, with the exception that some authors raise to the rank of a period the time that in Europe is assigned to the Lower Cretaceous. To this interpolated period in North America is given the name Comanchean.

	Europe		North America
MESOZOIC ERA	Cretacous period	Upper	Cretaceous period
		Lower	Comanchean period
	Jurassic period		Jurassic period
	Triassic period		Triassic period

In North America the uplift of the land mass at the close of the Carboniferous with the consequent complete withdrawal of the seas left practically the whole of the continent exposed during all of the Permian period and the early part of the Mesozoic era. Hence most of the rocks of these times that we now find exposed in North America were not formed as sediments in the seas but as accumulations on the land (continental deposits) formed either where the rivers flowing down from the higher lands poured their loads of detrital material into temporary lakes or spread them out onto the deserts on which they debouched and disappeared. Extensive continental areas are not as favourable for the prolific development of life as are the oceanic areas and the conditions attending the accumulation of continental deposits do not lend themselves to the preservation of the organic remains (fossils) as well as do the oceanic sediments. Hence, it follows that in the few Permian rocks that are preserved we do not have a very full record of the life of Permian time - a significant period which marks the close of the Paleozoic era or else, perchance, records the interval between the Paleozoic and Mesozoic eras.

Over most of the continent the conditions that prevailed in North America in Permian time were continued into the Triassic - the first period of the Mesozoic era. In the eastern part the old Appalachian trough or geosyncline had disappeared in the uplift at the close of the Paleozoic and in its place had arisen the Appalachian Highlands. These were being rapidly broken up into irregular mountains by the processes of erosion and the erosion products of Triassic time were being swept from the eastern

side of the highlands downwards toward the Atlantic ocean. Much of this detrital material never reached the sea floor, but was stranded on the flat plain at the foot of the plateau, or dropped into long valleys parallel the Atlantic coast. These accumulations form the continental deposits which are the chief clastic or sedimentary representatives of the Triassic in Eastern North America. In the same region there was considerable igneous activity resulting in some volcanic flows and in the injections of sills of basaltic or trap rock into the earlier sediments. This trap rock is probably best known as the rock of the palisades of the Hudson.

Over the rest of the continent, there was no marked invasion of the sea in the central part throughout the Triassic, but in the western coast area there was a land depression toward the close of the period, permitting an invasion of the sea which left its sediments deposited along strips of the western coast extending from Alaska, through British Columbia, to California in the south.

A general uplift at the close of the Triassic interrupted the deposition in this area, but the advance of early JURASSIC seas brought about a renewal of sedimentation over much of the same region. Towards the close of the Jurassic a strong thrust was developed along a northeast-southwest line on the Pacific side of the continent which lifted up much of the western coast area, and brought about the initiation of the Sierra-Nevada, the Cascade, and the Coast Range mountains. Accompanying this general revolution in the west there were great intrusions and extrusions of igneous rocks, largely of granitic type. Later erosion has exposed many of the intrusions in the form of bosses and large batholithic masses in those western regions most affected by the revolution. The igneous intrusions of this time are probably responsible for the introduction of much of the metallic deposits now worked in British Columbia and the Western United States.

In the eastern part of the continent there was little or no submergence in Jurassic time, and the upraised land continued to be subjected to erosion.

The uplift of the western side of the continent at the close of the Jurassic was followed in the early CRETACEOUS (Comanchean) by an invasion of the southern sea from the Gulf of Mexico northwestward. In later Cretaceous a lowering of the central land mass allowed this sea to extend northward till finally it made a continuous body of water from the region of the Gulf of Mexico to the Mackenzie delta. In an east and west direction this sea, at its maximum, extended from the Rocky Mountain belt to the border of the Canadian shield, and it covered most of what is now the prairie provinces and states. At different times and places the water in this inland body varied from fresh to brackish to salt. Along the western margin of the sea in its fresh or brackish stages - or areas - there were formed some immense coastal swamps from which have been formed the great coal deposits of the Alberta foothills and western plains. In addition to the coal deposits of definite Cretaceous age are some others in the Rocky Mountain area which were formed in an interior body of water which existed in either late Jurassic or early Cretaceous time. These are called the Kootenai coal formations and to them belongs the coal of the Crowsnest field in British Columbia.

Toward the close of the Cretaceous in both North and South America an uplift with some thrusting along the southwest-northeast direction,

elevated the great mass of the Andes and the Rocky Mountains. In North America the Rocky Mountain uplift brought up all the rocks that, with slightly interrupted successions, had been accumulating in the Rocky Mountain geosyncline from the beginning of the Paleozoic to the close of the Mesozoic. These rocks are now lifted high above sea level and are well exposed along the sides of the deep trenches and valleys that have been excised by post Cretaceous erosion. The same erosion assisted by faulting action has dissected the uplifted land to form the lofty isolated peaks of the Andean and Rocky Mountain ranges. This uplift may be considered as the feature which brings to a close the Mesozoic and introduces the next era - The Cenozoic.

THE CENOZOIC ERA

On the basis of the development of life during this time the Cenozoic is subdivided as indicated below:

- MESOZOIC ERA
  - Quaternary
    - Recent
    - Pleistocene (Glacial)
  - Tertiary
    - Pliocene
    - Miocene
    - Oligocene
    - Eocene

In North America the uplift of the western part of the continent at the close of the Cretaceous brought about a general retreat of the waters of the great inland sea already referred to. Parts of the western area, however, were at first so low or so poorly drained that they were covered with large sheets of water into which the erosional debris from the newly uplifted land was washed. These inland bodies of water favored the formation of great swamps and from these were formed another set of coal (or lignite) deposits. The later coal beds of Alberta and of Southern Saskatchewan were formed from these Tertiary swamps. Similar swamps in interior basis in British Columbia and the Yukon were responsible for some of the coal of those areas.

During all of Tertiary time there was considerable igneous activity throughout Western America. The most pronounced manifestation of this activity is probably to be found in the great succession of lava flows and ash beds in the western United States. In Washington, Oregon, Idaho, and California lava flows and volcanic ash beds are piled up to a thickness approximating 5000 feet and covering an area of from 200,000 to 300,000 square miles. Entombed in some of these accumulations are the remains of some of the old forests of that time, caught and buried in the standing position by the great falls of ash or the flows of lava. In the Yellowstone National Park may be seen a succession of seventeen of these petrified forests one above the other as each was buried by the accumulation of one stage of Vulcanism and succeeded by a new forest built on the fertile soil of the volcanic products which had already buried its predecessor.

The chain of volcanoes, some extinct, some dormant, and some active which extend from Alaska to the southern Andes and from thence westward across, and northward along, the Pacific to Japan, are some of the present manifestations of the volcanic activity which began in the early Tertiary, probably reached its maximum in the Miocene and is continuing to the present time. In Europe there was less volcanic activity but in India the whole of the Deccan plateau is underlain by basaltic rocks of this age. In some places these trap rocks reach a thickness of 10,000 feet.

The great elevations of land masses, which began in the Mesozoic, continued through the Tertiary and in some parts of the world have probably been maintained to the present time. Throughout the world the Tertiary seems to have been a period of great mountain building movements for in it were initiated or continued the elevations which gave rise to the Rockies, the Andes, the Alps, the Apennines, the Caucasus, and the Himalayas.

These great elevations of land masses of the whole world can hardly be said to have ended the Cenozoic era, for it is probable that some elevation is still going on and the Cenozoic has not yet been brought to its close. The wide extent of land masses consequent on the uplift may, however, have had pronounced effects in the modification of climate which have been developed in the later part of the era. During most of the Tertiary the climate would seem to have been mild and fairly uniform from pole to pole. Following the general uplift of the continents, however, the temperatures of the land areas at least began to drop appreciably and as a result there was developed in Pleistocene time one of the great ice ages of the world - an ice age which we may believe is still with us. Further discussion of this ice age will be deferred till later.

The life of the Mesozoic and Tertiary

Since it is largely on the basis of the life of these eras that the subdivisions of the eras are based, we will notice briefly some of the characteristic features of the life of these times.

Plant Life. At the close of the Paleozoic the great forests of the Carboniferous were characterized by the dominance of such plants as the giant horsetails, club mosses and ferns - the vascular cryptogams. Some of the gymnosperms were well developed and a few of the true conifers had appeared. In the early Mesozoic the same general types of plant life were continued but in the Cretaceous of the later Mesozoic a change in the land vegetation was produced by the appearance of the broad leaved flowering plants - the Angiosperms. Before the close of the Cretaceous there had developed some representatives of such well known modern forms as the palm, willow, beech, birch, and poplar.

Grasses. Beginning in the early Tertiary and developing rapidly there evolved a very important group of the flowering plants - the grasses. This group of plants is probably the most essential of all plants to the modern type of mammalian life - including man. In it are included all the grasses on which the grazing group of domestic and wild animals live and in it also are the cereal grains, such as wheat, oats and so forth, and such other plants as the sugar cane and bamboo. The grasses may have started in the moister parts of the earth, but they rapidly spread over the interior parts of the continents and soon were able to cover, as they do now, even the semi arid plains of all the continents. The effect of

this new type of vegetation on the development and spread of mammalian life on the continent is to be noted in the evolution of the horse, the ox and similar types and is reflected in the modification of the food habits of the human race, particularly in the temperate regions of the earth.

Animal Life. There was considerable modification in the various groups of aquatic invertebrates from the Paleozoic through the Mesozoic and Tertiary, but the most striking phenomenon of the later eras is the development of the vertebrates.

The amphibians had reached a dominant position in the Permian and continued into the Triassic as a very important group, but their dominance was yielding to a higher race - the reptiles. Some reptilian remains have been found in the Permian, but it was not until the Triassic that diversification in form and increase in numbers rendered them supreme in the animal world. This supremacy was maintained throughout the Jurassic and Cretaceous periods. Strange modifications and adaptations were developed in this group during the Mesozoic era. The reptiles, descendants from forms which, through their probable ancestors, the amphibians, came from the sea, now took possession of the swamps and adjacent land areas. In this environment they developed bodies adapted to life on the earth with the support of the body dependent on limbs. In most of the land types there were four legs present, but in one group - the dinosaurs - some of the race, even at an early period in their history, had experimented with and developed the bipedal habit. Though the front legs of this group were never completely lost, the continued lack of use in the carnivorous division of the dinosaurs caused the fore legs to be diminished to absurdly small dimensions.

Departing from the land habitat, some of the reptiles learned to take to the air, and developed body, wings, and tail suggestive of some of the earlier birds. The body, of course, was not covered with feathers, and the wings were web like, but they were distinctly creatures of the air with powerful wings capable of sustained flight. It is interesting to note that at the height of their development the flying reptiles were toothless even as the birds developing later became toothless in their time.

Other groups of the reptiles returned to the sea or water from which the amphibians had originally come and in this medium modified the shape of the body to resemble either fishes or aquatic birds.

It is evident that with all these modifications the reptiles must have developed very rapidly within the Mesozoic. There were some smaller forms appearing throughout the time, but some groups - particularly the Dinosaurs developed to enormous sizes. Before the close of the era the reptiles dominated the land, the sea and the air.

Although the reptiles were the dominant group of the Mesozoic some of the higher warm blooded vertebrates were beginning to appear as early as the Jurassic. In the rocks of this period have been found the remains of the first known birds - Archaeopteryx and Archaeornis - and in the Cretaceous are found the fossils of two other birds. The first birds were primitive in that they still had a reptilian tail and they had jaws with teeth but they were feathered - a feature suggesting warm blooded animals - and they were distinctly birds.

The mammals (the warm blooded group of vertebrates whose body is covered by an insulating coat of hair, fur, or wool, and who suckle their young) are represented in the Mesozoic by some fragmentary remains which indicate some very primitive members of this group. The primitive mammals of the Mesozoic are, however, a foreshadowing of the very rapid and widespread development of the next era. Whether it was due to the wider range of habitat made possible by the constant temperature of the body, thermostatically maintained, or to the greater care which members of this group give to their young, or to their greater ease of adaptability to changes of environment, we may not be sure, but in any case this type of vertebrate rapidly replaced the enormous reptiles of the Mesozoic, and, in the Tertiary and the Pleistocene brought to their present position of world dominance the various members (including man) of the mammalian class.

ECONOMIC PRODUCTS OF THE MESOZOIC AND TERTIARY

The economic products of the Mesozoic and Tertiary may be listed under two headings:

(A) Those of sedimentary formation, which were either laid down when the sediments were being deposited, or were formed later by some modification of some of the materials laid down with the sediments (e.g. Coal, Oil, and Natural Gas). The less modified sedimentary economic products include such materials as Building Stone, Gypsum, Salt and such material as rock for cement or brick making.

In addition to the non metallics, there must be included with the sedimentary group the very important placer deposits of the Cordilleran and Yukon-Alaska areas.

(B) Those deposits which were formed from ore bearing solutions brought into rocks of earlier or approximately contemporaneous age by igneous intrusions of Mesozoic or Tertiary times.

THE NON METALLICS OF MESOZOIC AND TERTIARY

We may consider first those products of group (A) which fall into the non metallic section.

BUILDING STONE: Although much of the rock of the Mesozoic and Tertiary is as yet unconsolidated, there are some stones of these eras which find local uses near their places of occurrence. Exceptional to this more or less local utilization is the former use of the "Brownstone" of the Triassic, which at one time had considerable vogue in the eastern United States. The "trap" rock or basaltic rock of the same eastern region forms an excellent road metal.

BENTONITE: Bentonite is a very colloidal clay formed by the action of water on the volcanic ash washed into the seas and lakes of Mesozoic and Tertiary times. It finds considerable use in various industries, but is perhaps even more important, in that, in disseminated form, it is probably the base of the most productive soils of the prairie provinces and states. On account of its colloidal properties, it has been effective in impounding and retaining for ages the humus and mineral salts that plants need for their growth. The same properties help the soil to retain moisture, under

semi-arid conditions of climate, for a much longer time than would be possible with a less colloidal type of soil. This feature makes possible the production of grain crops in some parts of the west where the annual precipitation is so low that other types of soil would support only desert vegetation.

GYPSUM: Gypsum occurs in beds of Triassic age and is mined or quarried in several of the western and northern states (Montana, South Dakota, Wyoming and Nevada).

SALT: Salt occurs in various Triassic formations and is of considerable importance in Germany.

COAL: Coal is one of the most important economic products of the Mesozoic and Tertiary.

Triassic: A small amount of Triassic coal occurs in Virginia, but there is none of much importance in the rest of North America.

Jurassic: Coal of Jurassic age, though not found in North America, occurs in important deposits in Europe and Asia (Siberia, China, India).

Cretaceous: The coals of Cretaceous age are second in importance to those of the Carboniferous. They occur widespread in the western interior and the western coast areas of Canada and the United States.

In Canada the coals of the Vancouver and Queen Charlotte Island fields are of this age as are those of the Kootenai (Crowsnest) and Peace River areas. A small amount occurs in Saskatchewan and in Alberta the Cretaceous coals occur in many and thick beds in the eastern Rockies and in the foothills and plains to the east of them. They underlie a wide belt extending from near Calgary northward to the Smoky and Peace river districts. In quality the coal varies from a lignite to a semi anthracite in those parts of the fields where the coal beds have been involved in the Rocky Mountain uplift.

Tertiary: The Tertiary coal is mostly of the lignite variety. Coal deposits of this age are found in the Gulf Coast region and in the states adjacent to the Rocky Mountains in the United States. In Canada they occur in southern Saskatchewan, in Alberta, British Columbia and the Yukon.

OIL AND GAS:

Cretaceous: Oil and Gas of high grade are found in Cretaceous strata in Mexico and the adjoining Gulf Coast region of the United States. The deposits occur also in the Rocky Mountain states through New Mexico, Colorado, Wyoming, and Montana, into the province of Alberta in the Dominion of Canada.

Tertiary: It has been estimated that about one half the world's supply of oil is derived from rocks of Tertiary age. Geographically the oil fields of the Tertiary are widely distributed. In the eastern hemisphere Tertiary oils are produced in the Dutch East Indies, Southeast Russia, and Rumania. In the western hemisphere the production is from California, Peru and the areas in both North and South America adjacent to the Gulf of Mexico.

Oil shales of the Tertiary of great extent are also potential sources of supply when economic conditions may warrant their utilization.

THE METALS OF THE MESOZOIC AND TERTIARY

The great invasions of igneous rocks in western America which were so pronounced in Jurassic and early Cretaceous, and in Tertiary times were of varied nature over the wide areas in which they intruded the earlier rocks. Hence, it is, that the ore bearing solutions which accompanied or followed these intrusions are of different character in different parts of the Cordilleran region of North America. The ores deposited by the ore bearing solutions usually carry some amounts of each of the metals mentioned later, but the percentages and values of each vary from region to region. Depending largely upon the metal for which the ore is mined, the deposits may be classed as: Gold, Gold-Copper, Gold-Silver, Copper, Silver-Lead-Zinc, with the metals content, as mentioned before, varying with the character of the igneous rock with which the ore seems to be associated.

It is difficult in a short space to specify and differentiate the ore deposits derived from igneous bodies of the Mesozoic from those of the Tertiary but in general it may be said that most of the gold, copper, silver and lead deposits of the Cordilleran region were introduced by Jurassic-Cretacous intrusions with minor amounts brought in by Tertiary invasions of the earlier rocks. The deposits of the coast range batholiths and some of the gold of the Sierra Nevada of California are probably of Mesozoic age, while the gold occurrences of Cripple Creek, Colorado and of Tonapah, Nevada seem to be associated with intrusions of Tertiary age.

The erosion of Tertiary time in the Cordilleran region and in the Yukon plateau was responsible for the wearing down of much of the uplifted and exposed rocks of the Mesozoic and perhaps of the early Tertiary time. The gold veins in these rocks suffered the same erosion as the including rocks but the insoluble gold was not carried away in solution and was left to accumulate with the fragmental, detrital material of the veins and enclosing rocks. With this material it was ultimately washed into the streams which were dissecting the uplifted regions. Most of the lighter detritus was carried on toward the sea by current action of the streams, but much or most of the gold, on account of its high specific gravity, was stranded in the beds of the creeks or rivers as they cut deeper and deeper. These concentrations of fragmental gold in the bottoms of the streams form the placer deposits of the Cordilleran and Yukon regions (page 52). Some of these placers have been covered by later lava flows and some have been removed by glacial action, but some have remained undisturbed under the stagnant bottom ice of the deeper valley glaciers. The latter deposits have been discovered with little difficulty. Some of them occur in the present stream gravels and some of them in the higher benches of the valleys, benches which represent old stream bottoms when the stream was flowing at higher levels before it had cut below these valley floors to its present level. The placer deposits covered by the lava flows have been, in many cases, discovered and exploited by piercing the lava which covers them, and it is probable that still others may yet be found below lava flows or below the glacial debris which in some places cover them.

THE PLEISTOCENE OR GLACIAL PERIOD

The latter part of the Cenozoic has been marked by a great elevation of all the known continental masses of the world. Accompanying this widespread elevation and extensive land exposure, there was a distinct change of world climate. Throughout most of geological time the climate would seem to be moderately warm over the whole world, with no marked subdivisions into climatic zones such as are now evident on the earth. In only a few instances, apparently, has the moderate climate of the earth been interrupted by colder intervals, and it would seem that these intervals occurred at times when relatively large land areas were exposed. The more important of these colder periods were in the Timiskamian, the Huronian, the Keweenawan-Cambrian, the Permo Carboniferous and the Pleistocene. Each of these colder periods was marked by the development in some part of the earth of great continental ice caps such as now cover Greenland and Antarctica. Little mention has been made of the glacial periods of the earlier geological eras, but since the Pleistocene period is still with us, and since the glaciers of this age are responsible for so many of the topographic features of the northern part of North America, we will spend some time on a consideration of its features. This last glaciation doubtless has had a marked effect on the development of mammalian life in the northern hemisphere and the economic effects are very important, but the present more obvious manifestations are in the surface sculptoring of those areas covered by the glacier, and we will consider particularly those effected in North America where practically the whole of Canada and the northern part of the United States were covered by ice in the last glacial period.

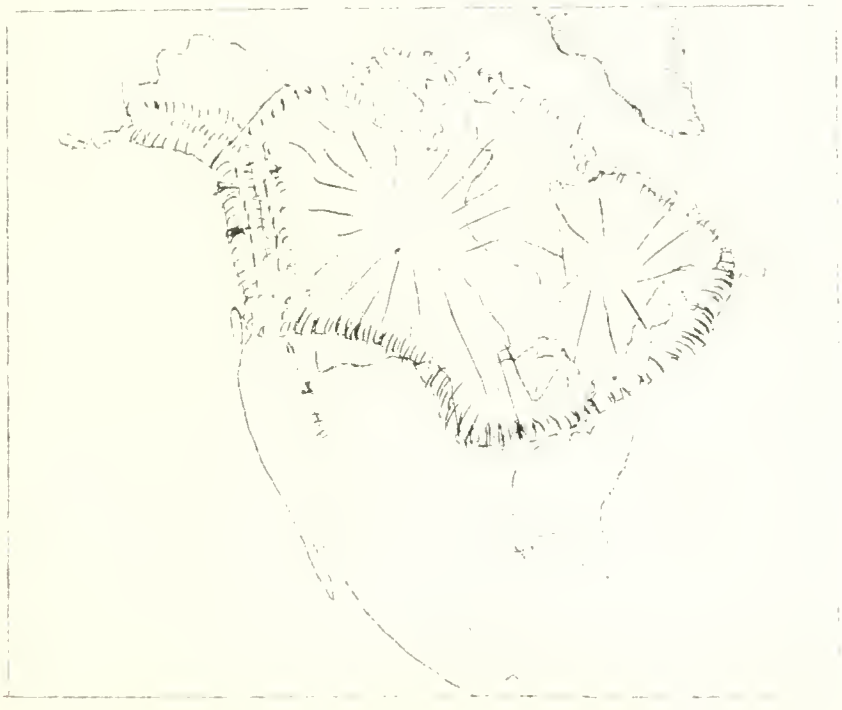
In the long ages of geological history of this northern area there have been many forces at work in moulding and carving its surface. The profound influence of even the oldest of these is still manifest in the major physiographic features of the country, but most of the local and superficial characteristics are due to the effects of the glacial ice cap which covered the northern half of the continent a few score to a few hundred thousand years ago. It is wrong, perhaps, to speak of the glaciers as the last sculptors of the glaciated surfaces, for weather, and wind and water erosion are still at work upon them, but, if we except these agents of the present, the glaciers were the last great sculptors of the surface of northern North America.

If you will turn to a map of North America or Canada it may help you to visualize the area over which the glacier acted and the directions in which it moved. If you have not such a map convenient, then let us - in imagination - soar away above the surface of North America to a point where our eyes - of imagination - may view the whole of Canada and the United States. From this point, if we look down on the continent on a midwinter night, we may see that its northern half is covered with a mantle of snow and ice. From our position we cannot tell how heavy this mantle is, but we think that it is only a matter of a few feet - and in some places of a few inches.

We expect that as a matter of course the snow will gradually begin to disappear toward the close of winter and that by the month of May practically all the snow and ice will have been removed with the exception of the glaciers of British Columbia and Alaska and a few patches of ice and snow in Labrador and the northwest barren lands.

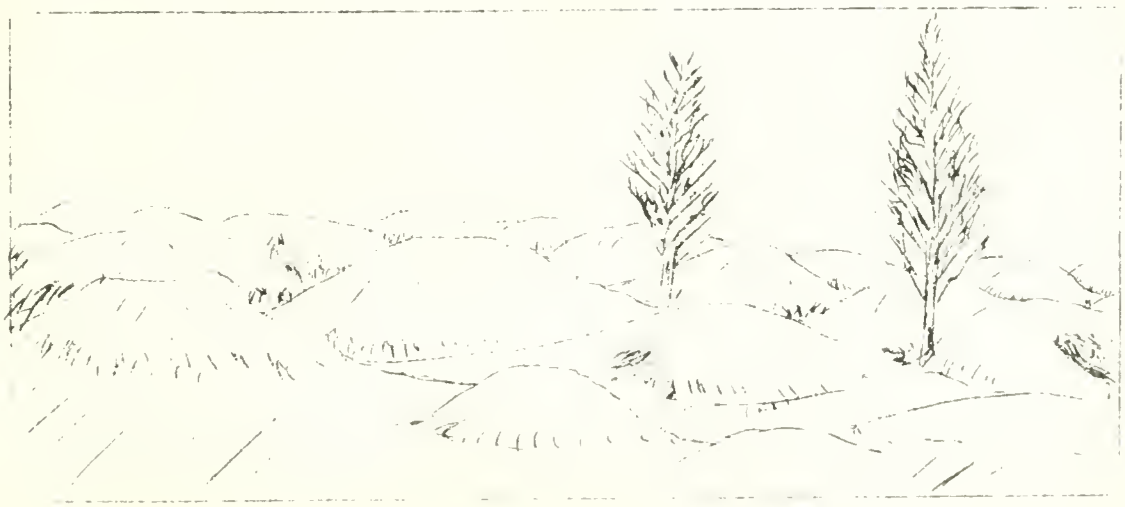
A million years or more ago at the close of the Tertiary, however, th climate began to get gradually colder than it had been and at last there came a year when the snow of the winter was not wholly removed at the clos of the succeeding summer. This condition continued year after year and century after century with the residual snow of each year added annually to the accumulation of all the years that had gone before. After many thousands of years there had thus piled up on the earth a burden of snow many thousands of feet thick. With the passage of the years all of this with the exception of a few score feet at the top had been solidly compacted into ice.

If the lofty viewpoint that we attained in imagination a moment ago, could now be moved backward in time for a few hundred thousands of of years, we would see, therefore, this accumulated snow covering North America as a thick mantle of ice from the Pacific to the Atlantic and from the Arctic seas to the valleys of the Missouri and Ohio rivers. This, we may note, is practically the same area as is covered with the snows of our present winters. In surveying this continental sheet of ice we would probably note that, although it was continuous from coast to coast, there were three regions where the ice seemed thicker or higher than over the rest of the area. These places were - the Labrador region, the Keewatin district, and the mountainous areas of British Columbia and Alaska. Moreover, if we could watch carefully enough and long enough we would see that the ice was creeping slowly away from these higher centres toward the lower margins. From the Keewatin centre it would be seen to be moving westward toward the foothills of the Rockies and southwestward and southward toward the valley of the Missouri. From Labrador it would be moving southward and southwestward across Quebec and Ontario toward the valley of the Ohio and its junction with the Mississippi. This creeping mass of ice was the last great continental glacier of North America.



If the range of our vision could be extended so as to penetrate through the glacier to the rock floor below it, we would see that the lower part of the mass was not pure ice, but that it included a great amount of mud, sand, pebbles, boulders, and blocks of rocks of all kinds. This material had been picked up from the rock floor over which the ice had passed and carried along with the moving glacier. As it was moved along within the ice the rock was crushed and ground to all stages of fragmentation, from the larger blocks and boulders down to a powdery mud, so fine that it is called "Rock Flour".

When the creeping ice with its included burden of rock and mud reached its southern margin, it found a region where the climate was warm enough to melt it as fast as it advanced. The water flowed away from this ice front and carried with it a great deal of the finer mud or "Rock Flour" but most of the sand, gravel, and larger blocks, as well as much of the included mud, was stranded along the line where the ice reached its southern limit. Year after year, and century after century this rock debris was delivered to the ice front and there left in unfashioned piles where the melting ice abandoned it. The accumulations so formed now appear as long irregular ridges or groups of ridges to mark the place where the ice front stood for so long. The name "Terminal Moraine" is given to these lines of irregular hills.



In the course of time the climate of North America - and of the whole world - became warmer again and now the ice at the front was melted faster than it was brought forward so that the front of the glacier gradually lost ground and receded toward the distant centres of Labrador and Keewatin Of course the recession was not uniform nor continuous. From time to time the climate became sufficiently cold again that the ice was able to make long stands at different fronts and along the lines of these successive fronts debris was again piled up in long ridges of irregular hills. These are known as "Recessional Moraines" and each indicates a place where the ice made a stand in its retreat.

At last the melting of the ice sheet was practically complete and nothing was left of it but the glaciers and snowfields of the higher mountains of the west and a few smaller representatives on the coast of Labrador. With the removal of the ice it is now possible to examine the surface of the continent so long hidden beneath the glacier and see what effects have been produced by this agency.

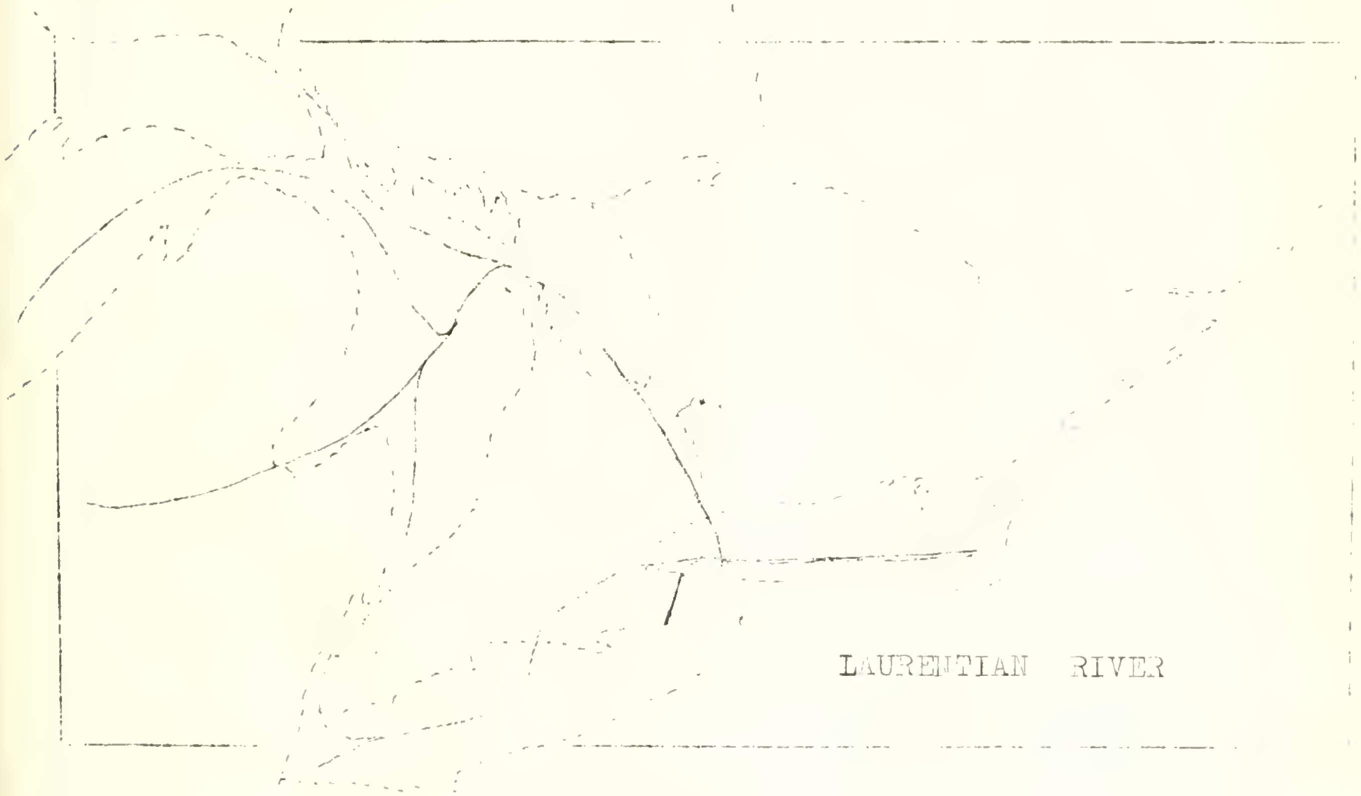
At the centres from which the greatest movement took place, that is, Keewatin and Labrador, we find that all the old soil and weathered rock has been completely removed and the rock surface is solid and bare of covering. Wherever the rock was a little weaker or less resistant the ice has been able to gouge out the softer material and depressions of varying sizes result. These depressions have later filled with water, or water and vegetation and so the innumerable lakes and muskegs of the far north have been formed.

As we go southward from these scored areas of bare rock and approach the old margin of the ice sheet we come to a region where the retreat of the glacier left stranded in place all the rock debris that the ice was transporting when the final melting overtook it. When the included ice was melted from this mass of boulders, pebbles, sand, and clay, it settled down to a hard, compact mass which we now know as "Boulder Clay" or "Hard Pan". This boulder clay forms the subsoil of nearly all the southern and more thickly settled areas of Canada. Its freshly ground up rock is the basis for a very fertile virgin soil, but the removal of the accompanying boulders which lay on the surface provided a gigantic task for the pioneers of the country and their families before this virgin soil was won to cultivation.

The surface of this boulder clay mantle is not always smooth, but is frequently rolling and may even have oval mounds of its own material built upon it. These mounds are usually elongated in the direction of the ice movement and are known as "Drumlins". Pits and depressions may also occur in the boulder clay often forming small ponds over its surface. On top of this layer of boulder clay will also appear at intervals the irregular broken ridges of hills, rather tumultuously arranged, the recessional moraines already referred to. These moraines often have local names such as "Oak Ridges", "Chestnut Ridge", and so forth. Associated with these ridges we often find deposits of gravel rather poorly assorted and formed by the water of the melting ice working over the debris of the moraine. These deposits - called "Kames" - give us many of the gravel pits of the older parts of Canada.

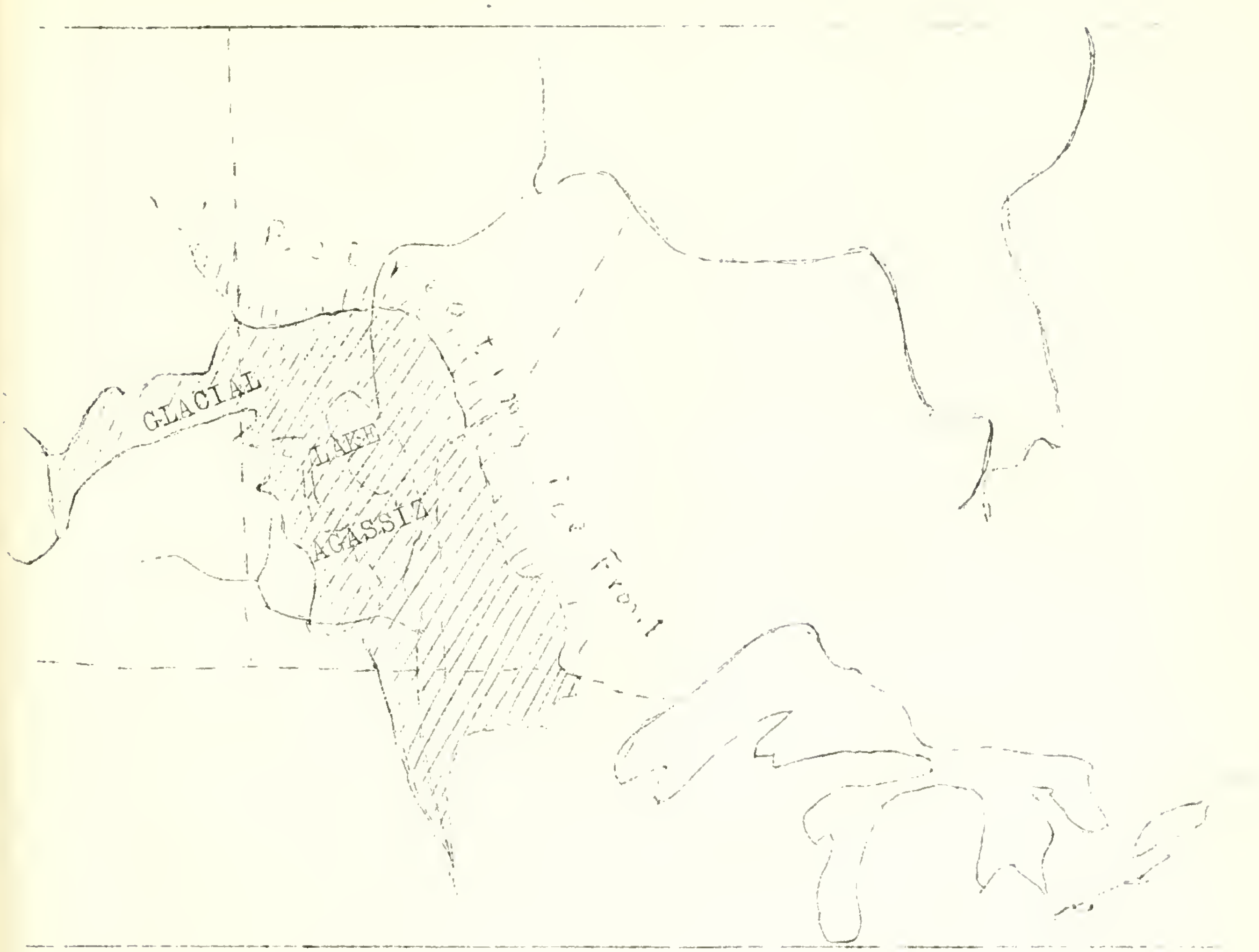
One other feature we may note - the modification of the drainage systems of Canada. Let us consider first the St.Lawrence system. In pre-glacial times there were no great lakes as we now know them and probably

no great rapids nor falls. The area occupied by the Great Lakes system was drained by a great river with its tributaries which flowed through their basins. The main stream flowed from the north through a gap between what is now Bruce Peninsula, and Manitoulin Island down through the Georgian Bay and Lake Simcoe valleys to turn eastward south of Toronto and flow to the sea along what is now the floor of Lake Ontario, and the St.Lawrence valley. Where it turned eastward it was joined by a large stream which probably entered the Ontario basin by a great gorge in the Dundas valley after flowing through and draining the Erie depression.



The debris carried by the glacier blocked the valleys and channels of these rivers in several places and caused the water to flood up the valleys behind the dams so formed and so make the present system of lakes. One of these dams caused the ponding of the water above Kingston and so flooded the Ontario section of the old valley - giving Lake Ontario. A barrier across the river which drained the Erie basin flooded that depression until the water was high enough to escape by a new route. This course was from the Fort Erie region to Queenston where the flood poured over the Niagara escarpment and so initiated Niagara Falls. In the years that have elapsed since then the falls have cut back through the rock to their present position. A dam of glacial debris to the southeast of the Georgian Bay section of the old valley caused a damming of the upper sections and the consequent flooding formed the bodies of water we know as Lake Huron and Lake Michigan. The waters of these lakes found their lowest outlet by way of St.Clair into the new Lake Erie and so over Niagara into the body of water occupying the Ontario basin.

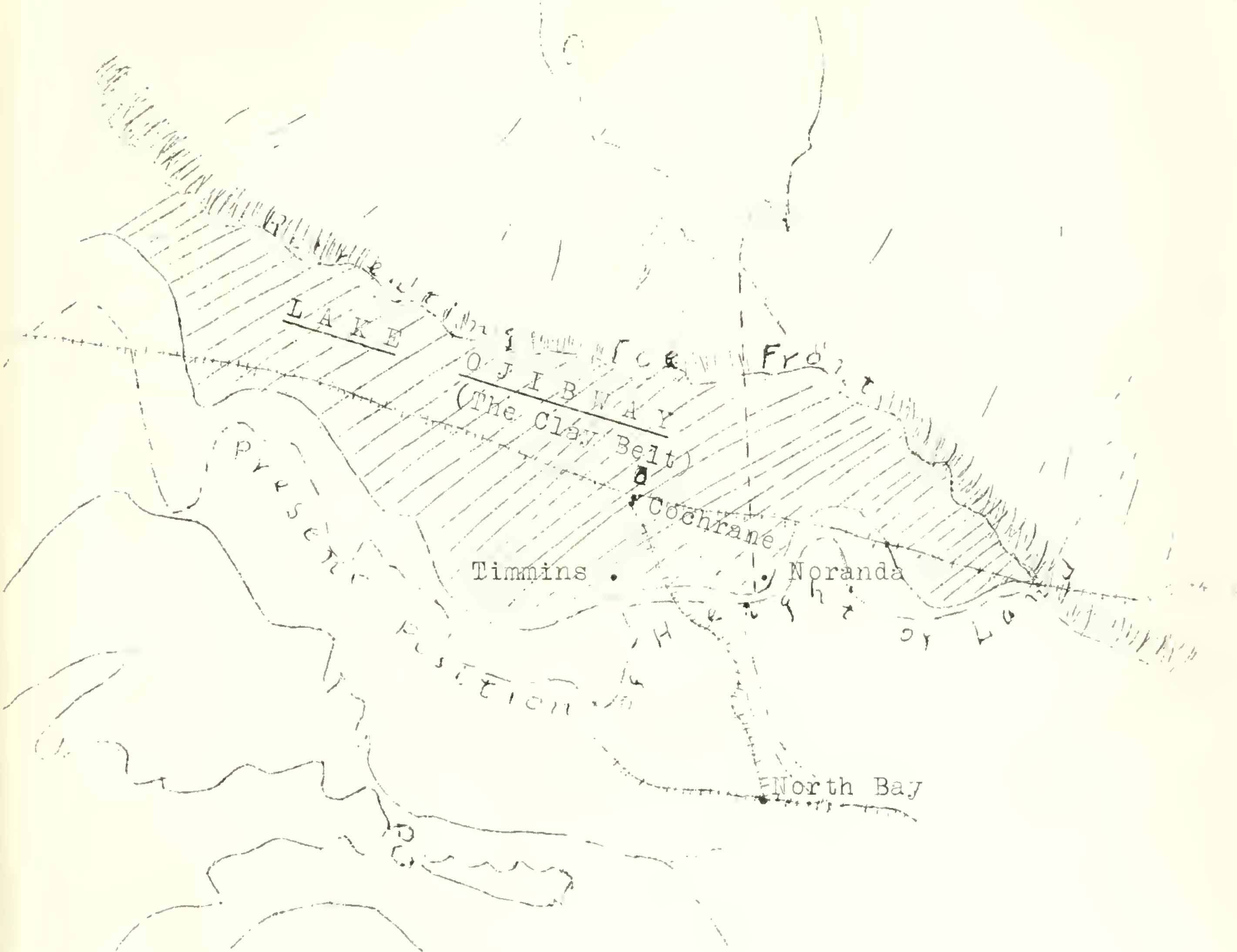
During the recession of the ice and before the present channels of the drainage systems were opened a number of temporary lakes were formed. Of these lakes only the mud deposited on their beds and the sands of their shores with their shore cliffs remain as evidence of their existence. At one time in its retreat from the south the ice of the Keewatin centre blocked the drainage which now flows from the Saskatchewan and Red river systems down the Nelson to Hudson Bay. The waters of these rivers were backed up till they formed a huge lake which occupied all the area eastward and northward of the Manitoba escarpment right up to the edge of the retreating ice. The muds poured into this lake from the waters of the Saskatchewan and Assiniboine have made the very fertile soils of the Red River Valley. The sands dropped at the mouth of the Assiniboine form the Brandon sand plains. The name "Agassiz" has been given to this lake. The water of the lake was made to escape southward from the upper end of the Red river valley to the Mississippi system.



GLACIAL LAKE AGASSIZ

In its retreat to James Bay the ice at one time formed a dam preventing the waters of the north from escaping in that direction and so made a huge lake extending from the ice front toward the height of land in Northern Ontario and Quebec. The mud deposited on the bottom of the lake forms the subsoil of what we now know as the "Clay Belt". Anyone who has seen the agricultural development of this belt where the Canadian National has opened it up for settlement will appreciate what this glacial lake has done in providing fertile farm lands in the northern part of these provinces.

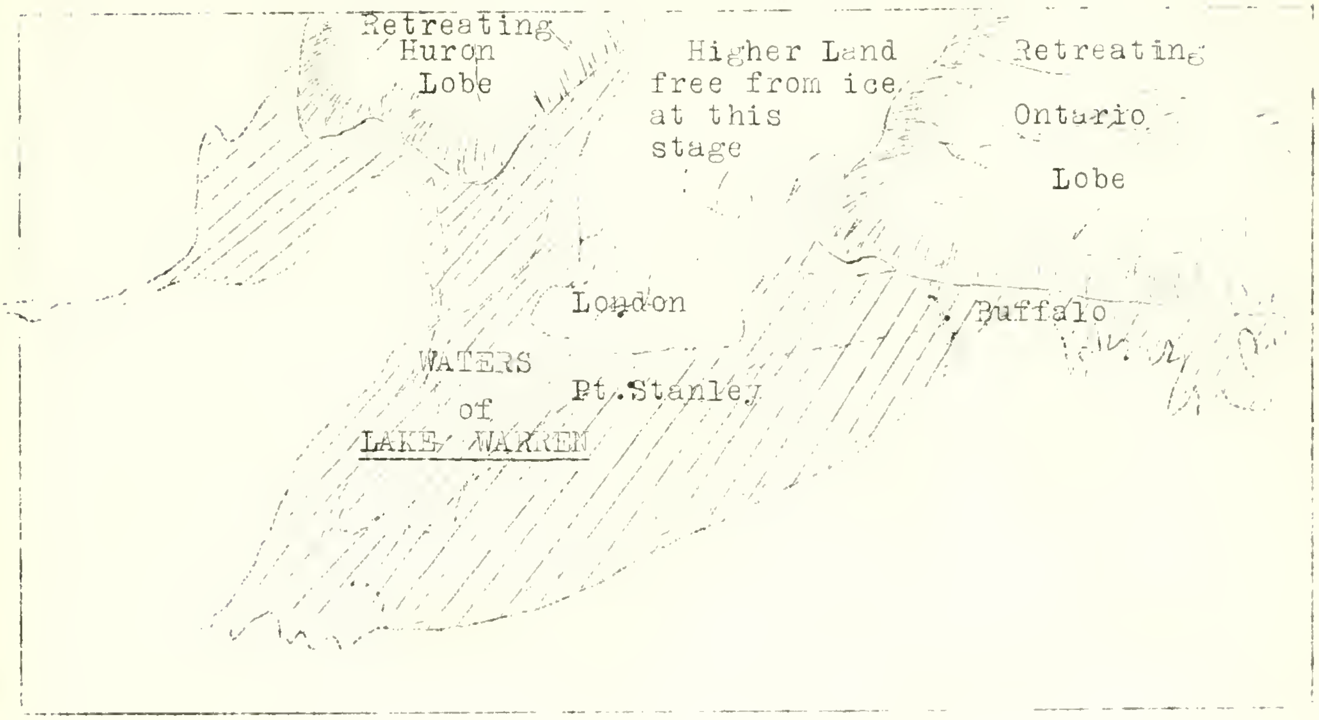
LAKE OJIBWAY.



In the southwest peninsula of Ontario the retreating ice at one time held its front along the region of the Niagara escarpment for some time and so prevented the water to the west from escaping to the Atlantic. This water was made to flood high enough to flow through a gap in the height of land to the west and so into the drainage system of the Mississippi. The lake so formed flooded much of the land to the southwest of Lake Huron and to the north of Lake Erie. The level land of Lambton county and of the counties bordering on Lake Erie is largely underlain by the deposits of this old glacial lake.

LAKE WARREN

One of the stages of the retreat of the Huron and Ontario lobes of the last glacial advance.



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In the preceding paragraphs we have discussed the development, the advance and the retreat of an ice sheet over the northern part of the North American continent. During the pleistocene period there were at least three and perhaps four of these ice sheets which developed and advanced till the whole of the area was covered, and then retreated until the country was perhaps as free of ice as it is now. The first ice sheet covered the area at a time probably a million years ago. After its recession the climate became fairly moderate so that at a place as far north as Toronto some plants which have at present an almost sub tropical habitat grew and thrived. After a large period of this mild weather the climate again became cold and a second ice sheet began to accumulate. In time this ice advanced over the same regions that had been covered by the first ice and all the warm climate plants and animals of the warm interglacial were either destroyed or driven southward before this second glacial invader from the North. Again the oncoming of a warmer climate brought about a withdrawal of the ice. It is probable that this withdrawal may not have been as complete as was the first, since no such warm climate plants are found in the interglacial clays of this time, as were common in the sandy deposits of the first interglacial aready mentioned. Once again the climate became colder and once again the ice moved southward to cover, in this third glaciation, practically the same areas that had been buried under the ice of the first two advances. This last glaciation probably had a shorter period of existence than either of the two previous advances

and it may be that it had no more than attained its maximum when a moderating climate caused it to begin its withdrawal. This withdrawal was rather reluctantly accomplished with intermittent periods of colder climate when the ice front remained stationary for many years. At each of these fronts where the glacier halted for a longer or shorter time, there was left a deposit of debris, which we now recognize as a recessional moraine. At present this ice sheet has withdrawn so that most of North America is free from permanent ice and snow. That the end of this last advance has not yet been attained is evidenced by the glaciers of the higher mountains on the Pacific Coast and by the ice cap of Greenland, as well as by minor ice accumulation in the higher lands of Labrador.

Since each of the successive ice sheets destroyed or reworked much of the deposits of the earlier advances, it follows that most of the features that have been described in the foregoing pages are manifestations of the work of the last glacial advance. This last glacial advance is called the Wisconsin.

Some of the economic effects of this glacial age have been suggested in the previous pages, but it may be well to summarize them here.

(1) Effects on Soils. A great deal of the residual soils over the areas underlying the glacial centres has been swept away, leaving the rock exposed as in the barren lands of the north west of Canada.

The glacier on the other hand, by the grinding up of fresh and unleached rocks, provided a mixture of clay and coarse fragments (boulder clay) which forms the basis of a soil rich in unleached mineral salts. Many of these mineral salts are desirable for plant growth, so that soils derived from a boulder clay subsoil are apt to be more fertile than the residual soils which were not affected by glaciation. The boulder clay soils are to be found along the southern margin of the glacier (outside the region of scouring) where the waning transportation power of the thinner part of the ice sheet was allowing debris to accumulate to great thickness in its base.

The soils underlying post glacial lakes were in most cases directly derived from the boulder clays with little or no leaching effect. These lake bed soils, as noted before, provide North America with some of its most prosperous farming areas (p.93).

(2) Drainage. The drainage effects have been already noted. An interrupted and renewed drainage system has provided the thousands of lakes of all sizes in the northland, as well as the great lakes of the St.Lawrence system and its rapids and water falls.

(3) Water Power Development.depends in northern North America almost entirely upon the great reservoirs of water - the greater lakes, with small annual fluctuations - and on the rapids and waterfalls of the rejuvenated drainage system developed by glaciation.

(4) Mineral Deposits. Glaciation has affected our mineral deposits in at least two ways.

(a) Previous to glaciation the long periods of weathering and erosion must have caused the alteration of the upper parts of many of the mineral deposits in the areas later covered by the ice. In many of the

ore deposits this alteration must have brought about secondary concentration in the upper levels of the deposit (page 54). Nearly all of the sulphide deposits would have had at the surface and for many feet in depth the characteristic features of gossan and other alteration deposits mentioned on page 59. The profound erosion due to glacial activity has removed all of these secondary enrichment and alteration products, so that now only the original primary minerals of the deposits are to be found. In most of the ore deposits of Northern Canada there is very little of iron gossan or similar features to mark the presence of ore bodies below.

(b) The same weathering and erosion factors which modified the upper parts of the ore deposits in preglacial time must also have served to develop many valuable placer deposits in the streams of northern Canada. The glacial advances removed most or all of these placer accumulations to mix them hopelessly with the general debris of the boulder clay. Some few placers may still lie deeply buried in some clay filled preglacial gorges, but up to the present no placer bearing buried gorge has been found in the glaciated regions of northern Ontario or Quebec.

(c) The glacier has been of some benefit in that it has removed the residual soil and loose debris from the surface of much of the mineral bearing areas of the north and in this way has rendered prospecting easier. Particularly is this to be noted in the great barren lands of the north west.

If we might revert for a moment to the effects of the glaciers on drainage, we may note that prospecting and freighting essential to mining are facilitated greatly in Canada by the presence of the innumerable lakes and waterways incident to the disturbed drainage conditions of glaciated areas.

THE FINDING OF A GOLD PROSPECT AND THE DEVELOPMENT OF A GOLD MINE

Balmer Neilly, B.A.Sc., M.E.

The above subject is a very comprehensive one to be treated in one evening's discourse, but it is apparently the one that has been selected by your group and assigned to me by the Director and his fellow conspirator, your Chairman. At their request I will, with your co-operation (and financial assistance) endeavour to find a prospect and to develop it into a producing mine in the course of this evening's lecture, leaving you later, I hope, in full possession and enjoyment of any possible dividends that may ensue from our one crowded evening's work.

Now I am in a bit of a predicament, because I never did find a gold mine and probably never will find one. However, I have been a prospector. As an examining engineer, I have followed many prospectors, and I have some experience at any rate in the development of mining properties, and in order not to embarrass my sponsors, I propose, with your permission, to draw upon my experience and imagination. Perhaps at this stage I should get under the brokers' umbrella and gravely tell you that "while the information I gave you is not guaranteed, it has been obtained from sources I consider reliable".

To make the matter concrete, and to give each member of the class a personal interest in this prospective gold mine, I can think of no better way than to ask you, to assist me in forming a prospecting syndicate. Owing to limitations imposed on most of you by lack of experience, lack of compelling interest, or lack of sufficient individual capital (or perchance lack of adequate personal freedom) it is probably impossible for every member of the class to assemble pack and pick and to go on a prospecting venture - hence the necessity for our prospecting syndicate.

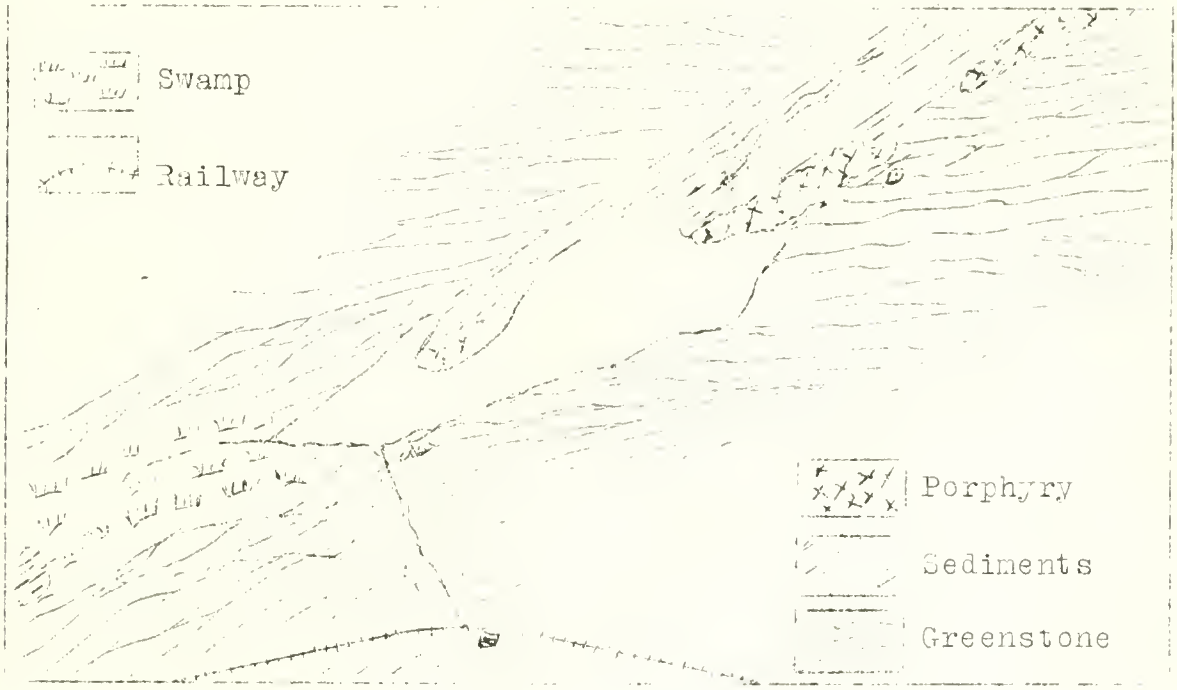
If you are content with the arrangement, I will be glad to facilitate matters by assisting in the organizing of the syndicate and to this end would ask you to proceed with the election of officers. Perhaps you will permit me to suggest the following slate: For President of the syndicate I would nominate your Chairman of this evening, and for Secretary (and Treasurer) may I nominate the speaker of the evening. If we may consider these elected we may proceed with the further business of calling on each of the members for the initial assessment of $10.00. With a syndicate of this size this will give us sufficient capital to carry on a modest prospecting campaign for at least one season. Having organized our syndicate so as to give each member of the group a personal interest in the project, we may proceed with the consideration of the problem of finding and developing a gold prospect.

Now if we are to succeed in finding and developing a gold mine in the course of say 45 to 50 minutes, there is no time to lose. Necessarily my story will be sketchy and perhaps lacking in sequence, but if at some stage your mind is troubled by my lack of clarity, don't be afraid to put your question to the Chair. If there is time at the conclusion, I will be glad, if possible, to answer any questions the Chair may entertain.

If we are to succeed in our quest, and we must, we must do some careful planning. We will start about January. The prospectors are clear of their previous year's agreements. They have probably enjoyed their holiday celebrations to the limit, and are ready to do business with, as they will describe it - 'the right party'.

Now I know a goodly number of the more successful prospectors, so to save time, and with the Chairman's guarantee that the salary and expense money will be provided as promised, we enter into an agreement. There are many kinds of agreements, but in this case we promise each of these men $100.00 per month, good equipment, and their expenses in the field, plus a 10% interest in anything staked to be divided between them as they see fit.

The next few weeks are spent in the study of government reports and maps and in gleaning information from any and every source available. Finally they decide to try an area represented or pictured by this map:



Now you will note we get to the jumping off place by rail. Immediately our prospectors arrive, they sort out their baggage, get it into the canoe, and away they go. They camp the first night at the entrance to the lake.

Almost as soon as the canoe has touched the shore, each man reaches for his axe. One underbrushes the location of the tent, throws the tent and gathers brush for the bed. While he is doing this, the other gets a supply of dry wood for the fire and starts the preparation of the evening meal.

The meal over, out come the pipes. The dishes are washed at the water's edge. A log or some other kind of comfortable seat is shifted close to the fire and in conformity with bush practice, few words are passed. Each slumps before the fire wrapped in his own thoughts.

The sun sinks below the horizon and with the afterglow, with all its glorious colors and shades, comes the evening calm broken only at odd intervals by a fish breaking the surface of the water, or the late flight of ducks seeking their evening rendezvous.

Finally the whip-poor-will us silent. A hush seems to envelope lake, stream and forest, descending and making its influence felt upon our prospectors even as a benediction.

Pipes are replaced, and with the last stretch comes the words - "let's go to bed", and soon slumber has cleared the mind and nature commences the task of bringing rest and renewed vigour to the weary limbs.

The next day our men reach the east end of the lake and their immediate objective. They enter the creek and establish their camp beyond the prying eyes of those who may pass, for, strange as it may seem, there is always an air of secrecy about a prospector's movements.

Now let us take another look at the map and ascertain why this particular area was chosen. You will note that Keewatin greenstone forms the general background. Near the camp is a tongue of porphyry, and north of that a small area of sedimentary rock is indicated.

Most of our main structure breaks in the North Country run northeast, southwest. The axis of the lake and river suggest an area of structural weakness that was easily gouged out by the glacier. The porphyry adds to the evidence, and our theory is further supported by the included sedimentary. A major break in the earth's crust was necessary to let the porphyry eruptive up to the surface. Mineral bearing solutions would have a good chance to migrate and deposit their metal content under such circumstances and it is attractive to the experienced prospector.

Our men go to work looking for vein outcrops along either margin of the porphyry tongue. They don't know yet whether in their search they should favor the porphyry or the adjacent greenstone or sedimentary rock. However, they are efficient, energetic, intelligent prospectors, and shortly after noon one partner is heard calling the other in an excited manner - "Come over here" - "Come over here". He has found quartz outcropping and is busily engaged in stripping the moss and overburden from the surface, and soon two picks are busy at the same job. Each piece of quartz, as it is pried out of place, is closely examined, and I will give you my assurance no person in the world can spot a speck of visible gold as quickly as an experienced prospector. At last they find a piece that leaves them hopeful and out comes the magnifying glass. Sure enough they have free gold. You can imagine their excitement. Again they go to work and disclose either wall. One prospector moves east on the assumed strike of the vein and uncovers the extension. His pick is moving up and down with a restless enthusiasm and at last he sits down to examine the piece of quartz and vein matter he has detached, and sure enough he finds his speck of gold.

Now if there is one thing a prospector likes better than one piece of visible gold in a newly discovered vein, it is two pieces of gold. Each piece found adds about $1,000,000 to the probable fair price for the claim or group of claims.

Before the day closes each man fills his hat with the decomposed part of the vein and carries it back to camp. While one man prepares the evening meal, the other is busy with his mortar and pestle grinding down the decomposed material. At last it is ready to pan, and down he goes to the water's edge. His partner can't stand the strain and he follows. In

quiet suppressed excitement they await the end product, and sure enough the tail of gold is there.

The meal is forgotten. Their whole mind is engaged in considering the possibilities of the discovery. One suggests that since the porphyry is shown on the map to extend at least a mile, the vein will extend that far. The other prospector is looking southwest and suggests that those geological fellows in Toronto and Ottawa may know something after all. He recalls that they suggested the main break was probably under the lake and he thinks they were right. Now of course the lake is 20 miles long and even if the vein only went half way that would give them 11 miles, and everybody now knows that mining operations can be successfully carried on to a depth of say 10,000 feet. Of course this assumption is accepted and they agree, before going to bed, to think not sleep, that their new discovery is more important than all the mines in Kirkland Lake, and on second thought it probably outclasses the sum total of Kirkland Lake and Porcupine.

Next morning they stake three claims each on their own behalf and another six claims on behalf of other license holders. They try to cover the strike, and if any dip of the vein is discoverable, they stake the parallel claims to protect their discovery in that direction.

The following morning camp is struck, and with the description of their claims as staked, and a few general samples and a description of the vein found, they are off for the steel and the Recorder's Office. At the railway they wire their principals to meet them at the Recorder's Office. At this conference, plans for the future are formulated. They may invite a mining engineer or company scout to accompany them back to the discovery, and let us assume the latter.

He examines the discovery and finds the vein carries gold. He finds evidence of fair widths and some promise of length and continuity. He offers to option the claims on behalf of his company.

Tonight we have no time to haggle about terms. He pays $1,000.00 down to compensate the Syndicate for out of pocket expenses to date, and as evidence of good faith on his part, and obligates his company to start work at once, to spend a certain minimum amount of money on development work, and if the results are satisfactory to pay at some future date or dates a specified amount by way of cash or stock ownership.

The prospectors have completed their work and move along, and our interest turns from them to the prospect itself.

Mr. Engineer gets a group of men on the ground without delay to strip the surface and thus gain all available surface knowledge of the discovery. He gets an experienced geologist on the ground to map the rock contacts and peculiar structural features. He may discover parallel veins and follow the same plan of stripping. He himself starts to cut samples and plot the results.

We have no time to consider failure tonight and we assume the vein shows a width in excess of five feet and values of say $10.00 over a length of say 200 to 300 feet.

The next thing he wants to know is the dip of the vein and whether or not the gold content shows continuity at depth.

He could ascertain this by sinking and drifting, but his option payments are coming due. Time is important so he contracts for one or more diamond drills. His first hole is probably short and fairly flat. The first intersection gives him an idea as to dip, and permits him to lay out his plan for drilling.

He plans a row of holes, the first hole at each set-up being at an angle of say 45 degrees and the second hole from the same set-up at say 60 degrees. This gives him not definite information as to values but a general idea in that respect. They give him valuable data on structure and widths. Let us assume that the results are considered sufficiently encouraging to warrant the option payment and further work.

The next step is shaft sinking.

This involves the establishment of more permanent camps, the purchase of a steam plant and all necessary equipment, the necessary arrangement for quick communication and, where necessary, the building of roads.

It is a rush job and requires what the French-Canadian calls lots of cash money.

Again we hurry along and without going into particulars let us assume the underground development is successful in outlining an ore body that can be mined and milled for a profit equal to the capital expenditure involved. It is a small mine now and its future size is dependent upon the results of future and further development work.

At this stage we are faced with two problems. If we are short of money, there are three major problems.

1. Capital
2. Source of available hydro or other power
3. Design of mill.

No comment is necessary on the first two. To solve the third, bulk samples of the ore are forwarded to some metallurgist or metallurgical laboratory and experimental work is continued until the method considered as being most practical is determined.

Mill design and erection follows, and when money and power are available we are ready to enter the production stage as soon as stopes are equipped underground to insure the steady supply of ore equal to the mill designed capacity.

Now just a word or two as to what a stope is. A stope is a block of ore that is being broken down preparatory to be raised to the surface for treatment. There are many different kinds of stopes, each designed to meet a given condition. We have insufficient time to describe more than one, and we will take the simplest type - the one described as a shrinkage stope.

With the timber in place and the chutes running, it only remains to fill the cars and then convey the ore to what is called the ore pass. From there it drops to the underground crusher and from there through a measuring device it is loaded into a skip and conveyed to the surface. From this point on there is a certain sameness in the process so far as the larger producers are concerned, and I am going to give you very briefly McIntyre practice, because firstly it is the best, and secondly I should know more about it than any other.

McIntyre No.11 shaft is 4150 feet deep. It required 28 months to sink it. It required the hoisting of 160,000 tons of rock and 40,000 tons of water. Blasting operations required 240,000 lbs. of explosives, and for timbering and lining the shaft 2,256,000 feet of lumber were required.

McIntyre use two skips, one going up and the other down. At the 4100 ft. level, 6 tons are dumped into the skip and away it goes upward, attaining a mximum speed of 5000 ft. per minute. The round trip is made in less than 5 minutes.

At the shaft head it is dumped into a bin and from there it passes through another crusher. From that point it is conveyed to a very large set of rolls, and from there to the tube mills where it is reduced to say 65 mesh.

At this stage it goes into the flotation circuit. Here the metallic particles are floated off as a concentrate ready for further treatment and the remaining four-fifths go direct to waste.

The concentrates are ground much finer than flour and the gold is dissolved out by the cyanide process. The gold is then precipitated from the solution; the precipitates are treated with acid and melted down into gold bars and then shipped to the Royal Canadian Mint at Ottawa. They refine the bars and report the number of fine ounces of gold and silver and the Department of Finance purchase and pay for the contents as certified by the Mint.

It is, as you will see, a very simple process by which you take that which in its natural state is useless and without value, and by a process you call mining and milling you extract about one-third of an ounce of gold out of each ton of ore and you supply mankind with something both useful and valuable.

ESTIMATING THE VALUE OF A PROSPECT

Summary of a Lecture by
R.A. Bryce

In most cases the prospect which is to be examined and valued may fall into one of two categories:

(1) It may be a prospect which has been located by prospectors who are the agents of a large operating company who may follow up the report of the find by examination, development and operation by the personnel of their own company, if these latter stages are warranted.

(2) It may be (as it is in most cases) a prospect which has been located by independent prospectors, or prospectors working for a syndicate who are not in a position to bring a promising property to the stage of operation. Each prospector or syndicate must then either find a purchaser for the prospect or enlist financial and technical aid in the development of the property to the point of production.

Since in the latter group will fall the greatest number of prospects to be examined, we shall discuss the problems arising in the examination and valuation of prospects of this type.

There are, of course, two parties to the deal which must be made with respect to any one of these prospects:

(a) The prospector or his agents.
(b) The party to whom he offers his prospect for a deal.

To each of these is presented one of the most important factors in any transaction - the personality and probity or honour of the other party in the deal. The prospector must consider, on his hand, whether the party to whom he brings his property is interested in the prospect from a mining or from a market point of view. Does he want a prospect which gives promise of making a mine; or is he merely interested in a property which he can sell to the public, to his own profit, with little concern for its intrinsic value as a potential mine? The latter type is likely to offer the prospector more alluring terms, both as to present cash payments, and future instalments for later developments. An experienced prospector is aware, however, of the danger that the expected market for the proffered shares may not develop and that the necessary financial reorganizations for further development work may leave him with no equity in the property.

On the other hand, any of the larger mining companies who may offer him a deal are primarily interested in making another mine out of his prospect, and are as much concerned in the physical development as the prospector himself. They will be disappointed as well as he, if the prospect does not ultimately make a mine. The first cash offer for the privilege of examination will probably be only a little more than the first cost of finding it, but this will give him another start for a new prospecting venture and he can feel assured that his old prospect is being given a fair test by experienced men.

Let us suppose, then, that the prospector brings his proposition to the office of a mining company that is prepared to do real work on any promising property. Here, for the company, begins the first stage of the valuing of the prospect, and, as stated before, one of the first factors is the character of the other party to the deal - that is, the prospector.

In the first place, is he known to the officers of the company? If so, is he known as a good prospector who has been able, in the past, to give unbiased (or nearly so) judgment on the worth of prospects in which he is interested? Of course a certain amount of optimism must be admitted. If he were not an optimist, he would long since have ceased prospecting. Likewise, however, the exploration branch of the company must be optimistic, or they would long since have ceased to look for new mines. So we may leave the parties at quits as respects optimism, although we may allow the company Engineer to feel that with the prospector lies all the optimism, and on his hand, the prospector may be inclined to feel that in the company and its officials is centred all the cloudy pessimism of the smoke gloomed cities.

With certain prospectors of experience and stable judgment, one might be inclined, without hesitation, to send an examining engineer to the property with little discussion, but in most cases; the problem of optimism must be considered, and as much information as possible as to location, extent of known breaks or veins and values, must be obtained.

If the prospector has taken time and trouble to make notes of all of these in the field, it is helpful. Otherwise, we must remember that distance does leave a hazy halo about the brightness of a prospect as it does with all other things, and in the mind's eye the one or two specks of visible gold may have propagated themselves to such an extent that gold showings cover the whole exposure, and the exposure which, when he left it, was about the length of two shovels and the width of one, may grow to twenty feet on the new mental prints which are developing from his original ocular negative. He is not always to be blamed. He will be as much surprised, and more disappointed than you when he shows it to you in the field and notes how the sides and ends of the trench have slumped in to cover the big showing that he thought he left.

Presuming that the prospector - or his agent - may not be so well known to the company, his proposition may require more consideration before talking of a deal, or making preparations toward examinations. A great deal of information may be acquired in the office which may well determine that examination is useless. The first item of this information is likely to be "Location", and the location query may have reference to two factors: (a) Geological relationships; (b) Transportation facilities.

(a) Geological Relationships

If maps of the area are available, they will be of great help in discussing this factor. For instance, if the area that the prospector is describint is shown on a good geological map to be in the middle of a wide area of granite, then the Engineer is warranted in entertaining a reasonable amount of scepticism as to its possibilities for most of the metallic minerals. If, on the other hand, the map shows the prospect to

be in or adjacent to strips of greenstone or sediments flanked by granite or intruded by porphyry, diorite, etc. (pp.67-69), the interest of the Engineer is likely to be somewhat stimulated.

(b) Transportation Facilities

The next factor to be considered is the factor of transportation. It may be that the prospect is adjacent to a railway or is in a position to have uninterrupted waterway transportation to the railway - that is, on a river or lake at a point which can be reached by water with no portage or transfers necessary between the prospect and the railway. In either case, the transportation facilities may be considered as fairly satisfactory for almost any type of ore. If, on the other hand, the prospect is a long distance from railway and transportation is difficult, then the type of ore is important. A precious metal mine does not need as much transportation in of material as a base metal mine would, so that transportation facilities that would appear feasible for a precious metal mine might appear hopeless for a base metal mine.

In illustration of some of the transportation costs that must be considered, it may be noted that for one mine it has been necessary to expend over $100,000 for the mere building of a road to the property. In another case ( ) the freight charges to and from the mine work out to approximately $75.00 per ton. In another mine ( ) all freight must be brought in during the summer months. In this case, to the initial cost must be added the cost of capital tied up in the holding of some supplies for eight months before their use. Another factor in this case is the precarious position in which the mine would find itself if the amount of supplies required were underestimated, or an unexpected demand for new supplies were to arise during the winter months.

Let us suppose that the Engineer is satisfied with the information that the prospector has given him, and the information that he has obtained in the office warrants him in believing that there is a probability that the prospect offered him is worthy of examination. Under these circumstances, he may make arrangements with the prospector to visit his property. On his journey to the ground he will have carefully noted the problems of transportation and will have determined whether or not these are as feasible as the prospector probably has told him, and as he may have been led to believe from the examination of his maps in his office. The prospector will, of course, have tended - perhaps quite honestly - to minimize the difficulties of access to the region but the Engineer will bear in mind that transportation facilities which are quite feasible for one or two men with canoe and light camping equipment, may be quite inadequate for the movement of machinery and other equipment necessary for the proper examination and future development of the property.

Having satisfied himself that transportation problems are not insuperable, the Engineer will next proceed to his examination of the prospect. Of course, it would be an exceptional Engineer who could withstand the instinct to examine any prospect, once he was on the ground, even although his observations up to this point have tended to discourage his hopes for the making of a mine in that locality. Presuming, however, that the Engineer, up to this point, is satisfied as to locality, transportation, etc., he will next proceed to examine the ground. Without doubt, the

prospector will first wish to show him his discovery, and any other favourable indications that his development work up to this time has exposed. The development work will likely consist of some stripping and some trenching along the line of what the prospector thinks would be the extension of his original discovery. Here it may be said that one of the common weaknesses of the prospector in the Canadian shield is to be neglectful of the impression that a sloppy set of trenches is apt to have on the mind of the examining Engineer. In other words, the prospector neglects to "dress up" his property in a legitimate way to appeal to the eye of an examining Engineer. His trenches are apt to be too narrow, and to have not been continued to sufficient lengths, so that by the time he has returned to them, the sides have caved in and the Engineer is delayed by the necessity for further cleaning off the showing which the prospector assures him lies in the bottom of the slumped in trench. The delay is not conducive to a good frame of mind in the Engineer, and although all Engineers are honest and impartial, yet even here, we must remember that at heart the Engineer is a human being, and even with him, small irritations may have some influence in determining his conclusions.

When the trenches are ready for examination the Engineer or his assistants will probably do some preliminary sampling. While the assistants are employed with this task, the Engineer himself will probably be making rapid reconnaisance of the geological features of the property, and probably the general geological structures of the surrounding area. The preliminary samples may be sent out for assaying if conditions permit, and if the returns from these assays, and the geological layout warrant, it is probable that the sampling crew may do some blasting to get representative samples from fresh rock. It is probable that at this juncture some definite terms of a deal may be made between the prospector and the company. In general the deal would be such as to give the prospector a cash payment of say,$1000.00, for the privilege of more extensive examination of the property, with an option for further work or purchase of the property at some agreed price, if the company is satisfied as to the value of the property, and should be desirous of taking it up.

Assuming that this preliminary examination of the property has led the company to consider it a promising prospect up to this stage, the Engineer will probably wish to consider more carefully all the factors which must be taken into account in the ultimate operation of the mine. For instance, the factor of transportation has been accepted as tentatively satisfactory, but now will arise the question of the actual cost per ton of freight delivered to or from the mine, and a translation of this freighting cost into terms of cost per ton of ore mined and milled. This may be illustrated by the conditions obtaining at one of the outlying gold mines in Ontario where the cost of freighting supplies and transportation of material and men into the mine has worked out to a rate of $1.00 per ton of ore. The significance of this charge may be realized when it is noted that in many cases this additional cost to the mining and milling would make the difference between a mine that could be operated at a profit and a mine that must ultimately be abandoned. Here, also, we may repeat that the factor of transportation cost would be a more serious problem in dealing with base metal mines than in dealing with the precious metal mines. The other factors that must now be estimated in a more careful fashion are those of power, fuel and water.

POWER

In general, in Northern Ontario and Quebec the problem of power for a large mine can easily be solved by the development of Hydro-electric power, since in most cases water falls or rapids sufficient to develop adequate quantities of power are usually to be found within feasible distances of any mineral area in these provinces. If power is available from an established line belonging to an outside Company, the charges for this power may be estimated from the rates submitted by the operating Companies. If, on the other hand, it is necessary to install a privately owned generating plant at the nearest available water falls or rapids, the Engineer will be under the further necessity of obtaining an estimate of the total cost of power plant and transmission line, and of then calculating a reasonable annual charge, based on capital cost and maintenance charges. This annual cost must then be charged against the tonnage of ore produced. In most regions of Ontario and Quebec the power delivered from one of the established transmission lines would range from $30 to $100 per horse power. Of course it is quite probable that the higher figure may be exceeded, but it is highly improbable that the cost would be any lower than the $30 mentioned.

If the property is too far distant from available transmission line or power site, or if the production of the mine does not warrant the initial capital expense of the necessary transmission line or power site, it is, of course, always possible to secure power from steam or internal combustion engines. This latter source of power must always be more costly than electric power if the property is to be operated over a long period of time. Fuel for steam engines which at first sight may seem to exist in unlimited quantities in the heavily wooded areas which surround the mine, has a fashion of vanishing almost miraculously into the devouring maw of the boiler furnaces, and the cost and transportation of fuel oil for Diesel engines, the most efficient of the internal combustion type, brings the cost per horse power even beyond the higher figures for Hydro-electric power (in some cases the common range of cost for Diesel power would be from $75 to $90 per horse power.)

FUEL AND TIMBER

The problem of fuel in the areas we have been discussing must become a serious one when we consider the long and severe winters that are a climatic feature of these regions. Not alone must the heating of the mine and mill buildings be considered, but we must also think of the heating of the camp buildings and residences. In general there is available a sufficient amount of fire wood in the forest to at least temporarily take care of these fuel needs.

While considering the problem of fuel resources, we may note also the fact that in the securing of fire wood it may be possible to secure a considerable amount of mine timber necessary for underground working and timber for the construction of the mill and mine buildings. All of these features the Engineer will have been noting while he was calculating the available sources of fuel.

WATER

Fortunately, the water supply for mine operation in the Canadian shield is so abundant that we rarely have to consider it seriously as one of the determining factors in the problem of successful operation of a mine. Paranthetically, however, it may be noted that in some desert regions there are ore deposits which would make very successful mines if an adequate water supply for mining, milling and domestic requirements of the mining camp were available.

....

Presuming that all the costs which the Engineer has been considering would not be prohibitive for normal mining operations, further examination may be continued. The next stage of examination is likely to be by diamond drilling, and here will occur the first test of the present transportation facilities, for, in order to initiate this campaign, there must be brought in to the property all the diamond drilling equipment and all the food and other supplies for the diamond drilling crew. It is true that diamond drills are now available in forms which may be transported by pack horses or by aeroplane, but for the larger standard types some type of road is usually necessary.

In the diamond drilling it is probable that the first holes will be set to intersect the vein or probable ore deposit at shallow depths with the second set of holes to intersect at greater depth, and the third set to determine the extension of the vein or ore body along the strike. It must be remembered that the information from the diamond drilling, while valuable and essential, must not be considered as absolutely representative of the actual condition of the ore body. At best, each diamond drill intersection is the equivalent of but one channel sample, and no Engineer in charge of underground operations would be satisfied with the small number of channel samples that is made possible by the few diamond drill holes that are ordinarily put down. In one case three diamond drill holes have intersected an extension of the ore body and the highest results of the cores was only $1.29. Drifting on this ore body later proved that the ore was of good grade, but that each of the holes had intersected it at lean spots. Of course, it is true that in large sulphide bodies the chances of erratic results are less than in the case of gold bearing veins, but still it is to be remembered that too much confidence must not be placed in the results obtained from diamond drilling. Information as to the geological factors of rock types, fractures, and veins is generally reliable, particularly if the holes have been surveyed for at least their dip, if not their direction. But, as before mentioned, information as to values must be held as purely tentative until these values are actually checked by later underground work.

If the ultimate results of diamond drilling indicate the probable extension of the ore in depth and length, then the next step will be to explore the ground by underground operation. This brings us to the question of shaft sinking, drifting and crosscutting.

It is quite probable that in the less accessible regions the roads provided for the bringing in of a diamond drill will prove inadequate to the burden that will be placed upon them for the transportation of the plant and other equipment required for shaft sinking. This plant will

include steam engines, or other type of engine for power, compressor plant, hoisting equipment, blacksmithing and steel sharpening equipment, and all the other machinery essential for proper prosecution of underground work. If the shaft is to be carried to any depth the power plant, compressor, etc., may not be very much different from the equipment which would be required for the operation of a moderate sized mine. Hence, on a prospect which has only been proved by diamond drilling results and surface trenching, we will require a capital outlay which is comparable to that required for a moderate sized operating mine. In the building of roads and the purchase or chartering of boats, it may be necessary to spend as much as $100,000 before even starting to work on the shaft sinking and underground exploration.

The cost of shaft sinking varies, of course, in different regions, and also varies with the character of the rock encountered. In general, a charge of $100 per vertical foot is a reasonable estimate, and this would mean that we would have a preliminary charge of at least $50,000 for the sinking of a 500 ft. shaft, which is a moderate depth for underground exploration. Unless the shaft has been sunk on the vein and in an attempt to follow the vein, no underground exploration will have been done by the making of this hole in the ground. The actual underground exploration must be prosecuted by lateral work from various levels in the shaft, directed in such a manner as to intersect the expected continuation of the ore or vein in depth. By lateral work we mean tunnels which are opened in the rock along horizontal lines. When these tunnels are at right angles to the direction of the ore body, they are called crosscuts. When a crosscut intersects the vein or ore body it is customary to drive a tunnel or tunnels along the extension of the vein at the level where the crosscut encountered it. These tunnels which are made with the purpose of following the direction of the vein are called drifts. In the underground exploration it is probable that we would endeavour to intersect and explore the ore body or vein at 125 ft. vertical intervals so that from the shaft we would have a series of crosscuts and drifts at 125 ft., 250 ft., 375 ft., and 500 ft. depths. Each one of these series of workings is called a level. As in the case of shaft sinking, the cost per lineal foot of crosscutting and drifting will vary, but we are probably close to an average when we suggest a price of $20 to $25 per foot for the lateral underground working.

The purpose of the lateral work underground is the exploration of the ore body or vein for continuity and values at depth so that the lateral work, particularly in drifting, must be accompanied by very careful sampling of the rock through which the drift is passing. This sampling is done by cutting channels across the face, that is, the end, of the drift, every time a round of rock is taken out, and in addition, at regular intervals along the back (the roof) and walls of the drift. In the crosscuts it is also wise to take samples regularly in order that no possible minor or inconspicuous vein may be overlooked. This collecting of samples is the final work in the estimation of the probable value of the property, toward which all the other work has been practically preliminary. In passing, mention might be made of the problem of computing the values as obtained from the large number of samples that may be taken from any ore shoot (a part of the vein in which the values are consistently of ore grade for considerable distances without interruption). It may be found

that the samples will range in value from zero to $8.00 to $20.00 and even $100.00. Sometimes it is suggested that all parts of the samples carrying free gold should be discarded before submitting the sample for assaying, and again, some individuals hold that all the high grade values in the assay returns should be discarded in making up the average for the ore shoot. Obviously, neither of these procedures can be much more accurate than the inclusion of the high grade in the samples or the including of the high assays in the computation, for it is evident that in later operations the free gold particles will go to the mill and add their value to the general value of the ore. One method which has been found fairly satisfactory is to compute the assay returns from a large number of samples, e.g. 800, including all assay returns received. This average, we will say, works out to $25.00. All the high grade values are then reduced to this average figure, and on this basis the average value recomputed. The result of recomputation in the instance cited gave an average value to the ore shoot of $16.00. Later, milling returns checked very closely with this value. It has been found in some cases that the final mill run of ore shoots so computed tallies very closely with the average figure obtained by this method. Of course, it is to be remembered that a method of computation for one ore shoot may have to be slightly modified in being applied to another vein or ore shoot.

RAISES

When, by the means of drifts, the veins or ore bodies have been outlined on each of the levels, the next process is to determine their continuity in the regions lying between levels. To do this, raises are put up from one level to the next, the raise following the ore body. A raise is simply a more or less vertical opening extending upward, generally from one level to the level above. If, by means of raises, the ore body has been found to be continuous through one or two levels, the ore may be said to be well outlined in those areas bounded by the ore exposed on the levels and in the raises. To ore which is thus outlined is given the name "Ore in Sight" or "Developed Ore". To ore which is indicated only along the level, without delimitation in vertical extent, is given the name "Indicated" ore. A further classification is sometimes suggested where ore has been penetrated by the drill, but has not yet been exposed by underground work. To this class is sometimes given the name "Probable" ore. It is not felt safe to assume that single diamond drill holes, especially in gold bearing veins, can give definite proof of continuous ore bodies. Ore may be hoped for in these places, but until the drifts have proved the continuity of this ore, it must remain only "Indicated" ore, and until it is further proved by raises through the ore bodies, it cannot be called "Ore in Sight" or "Developed Ore".

MILL BUILDING

Presuming that the underground operations have developed sufficient ore and have indicated a further reserve of indicated and probable ore to warrant continuous operation over some time, the next step in the mining operation is the building of a mill. Until such developed and indicated ore has been outlined, there should be no attempt to proceed with the erection of a mill. It is true that in some cases the optimism of the

operator or the propaganda mentality of the developing Company may cause them to proceed with the building of a mill before any reasonable amount of ore has been outlined, and many thousands of dollars have been lost and many possible mines wrecked through the diversion of capital that should have been used in underground development going to the erection of a mill.

Our next problem is to determine the size of the mill that would be the most efficient for the handling of the ore under the conditions as indicated by: first the amount of ore indicated, and second the character of the ore. If the mine is a precious metal mine, e.g. gold, the problem of recovery will depend, to a large extent, on the character of the gold. For instance, it may be coarse gold or very fine gold. The coarse gold is usually what is called the free milling type. The very finely disseminated gold may be so fine that it is necessary to grind or crush the rock to a powder finer than ordinary flour before the gold particles will be freed from the surrounding rock, or, if enclosed in a rock particle, will be exposed along some faces of that particle to the action of the solutions which are later to be used upon them. For instance, with some types of ore it is possible to remove a large amount of the gold with a preliminary grinding and concentration at 65 mesh, with finer grinding for the residues. With other ores it is necessary to grind everything to 200 mesh or 300 mesh, if possible. It is evident that milling equipment for the latter type of ore must be more extensive than for the former. Again, the period that the ore must remain in solution may vary. In some cases the most of the gold is removed after the ore has been in circuit for a comparatively short time, while in other cases the time may have to be doubled to effect the same extraction. In dealing with an ore which requires a long period of time in circuit, it is obvious that a larger mill with larger or more tanks must be provided to handle a given number of tons per day.

Bearing all these factors in mind, the designing and building of a mill may be proceeded with, generally in consultation with milling experts. Usually it is wise to plan for a smaller mill at the beginning, leaving the problem of a mill of larger capacity until a few years' work has determined the type of milling best suited to the ore and the probable ore output of the mine. The cost of a mill to handle a moderate tonnage would range from $200,000 to $400,000.

With the building of the mill, the mine may be said to be ready to go into production, and it is probable that the total cost up to this stage for a small mine would not be under $500,000.

OPERATION COSTS

With the coming of the mine into production, there now arises the problem of further costs which may be more complicated than would appear at first sight. The wage roll, of course, is an obvious cost, and this will vary with the location of the property and the living conditions which are incident to the locality. In general, the wage rate in the mining industry is the highest of any industry in Canada. A second cost to be charged against the ore is the tax imposed by the Municipal, Provincial or Federal Governments. The third cost is the charge that must be set aside for Workmen's Compensation, in which may be included the fund to be set aside for minor and major injuries, silicosis, and other pension funds.

In conclusion, I may illustrate the difficult problem of estimating the value of not only a prospect but an operating mine, by referring to an incident that took place in the early days of the Cobalt camp. A highly placed Mining Engineer from one of the great mining Companies of England was sent by his principals to look over the Cobalt camp, and, if it seemed wise to him, to purchase some property or to make investments in one or more. One mine in particular was investigated by this Engineer. The owners of the mine set a price of one million dollars on the property. Expert as this Engineer was, in examining and estimating the values of mining properties all over the world, he was not able to make up his mind as to whether the mine was worth this sum or not. Ultimately the proposition was turned down, and yet that mine, in the rest of its life, turned out over seven million dollars in silver.

Incidentally, this difficulty of estimating the value of Cobalt properties has proved a great boon to the Canadian investors in mining properties. Outside capital, unfamiliar with the silver occurrences of the Cobalt camp, hesitated to venture any appreciable sums on investments in that camp. The result was that the ownership was held among the original prospectors and their backers. These men, mostly Canadian, as a result, received practically all the profits from the Cobalt camp, and this money has since been turned back into the mining camps which have been developed later, so that to the original capital contributed from Cobalt operations, we owe most of the Canadian investments in the Timmins, Kirkland Lake, and other mining areas of Ontario and Quebec. It is well to pay this tribute to the old Cobalt camp as the founder of our present Canadian mineral industry.

UNDERGROUND OPERATIONS

C.G. Williams, B.A.Sc.

It is needless to say that any discussion of underground operations in the space of time at our disposal must be of the sketchiest possible character, and with no attention to technical detail. I understand that a considerable number of those attending this series are interested from either the investor's or a business point of view, and in thinking of what I should say tonight, I have tried to keep that in mind.

After consultation, we decided it would best serve our purpose to briefly describe the various operations underground and then, if time permit, to more thoroughly examine certain phases which might be of particular interest to you.

Assuming that a property has responded favourably to preliminary development, it then becomes necessary to check those indications by work underground. In mountainous regions, access to underground workings is often made by adit or tunnel; but here in the east, either vertical or inclined shafts are used, depending on the circumstances. With flat dipping veins, especially in preliminary work, the incline is often selected; but for fast hoisting, permanent production work, the vertical seems most suitable. True, in some South African and Michigan mines, very high speeds are attained on inclines; but, generally speaking, the vertical is more satisfactory. The location and size of the shaft is decided on from the information gained in the preliminary work, and also from its proposed use as a future production shaft or as a preliminary exploration opening.

Usually a lift of from four to six hundred feet is decided upon as a starter, with level stations being set off at intervals of from one hundred to one hundred and fifty feet, according to conditions. I regret that I must always keep repeating that decision on nearly every question must be made "according to conditions encountered." Unfortunately ore bodies are not nice tabular veins with clearly defined walls, but are extremely variable in shape, continuity and value; and no two of them are exactly the same. We decide the level interval as a compromise between two factors. It costs a very considerable amount of money to develop a level on the one hand; and, on the other, if they are too far apart, valuable ore bodies are apt to be missed between levels, and the cost of extraction and difficulty of working is somewhat increased.

With our shaft lift completed, and levels turned off, we run crosscuts out to encounter the vein or veins on each level, and then proceed to follow these veins with as many machines as our facilities will permit. Following these veins is not always as simple as it might appear; but, by careful sampling and observation of faces, with the correlation of results above and below, and the assistance of the diamond drill, it is usually possible to keep reasonably on the ore. As this will be discussed in detail later, we need not go further into this question now. Drives are usually made 5' x 7' or 6' x 8' depending on probable size of production cars; and ordinarily no attempt is made to clean ore to the walls in the preliminary work.

To face page 115.

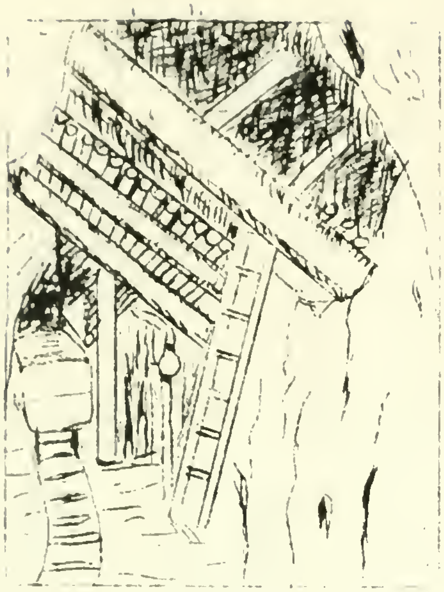


FIGURE 1A.

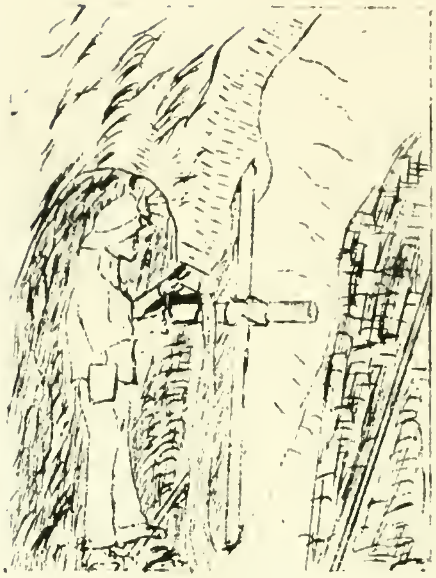


FIGURE 1C.

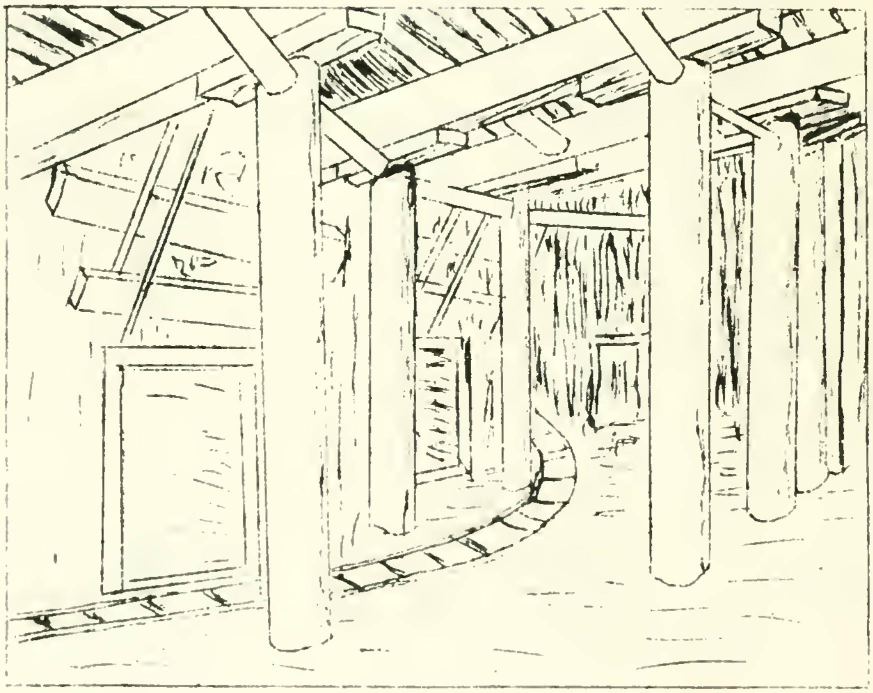


FIGURE 1B.

Typical Stope Timbering

Now, if we are fortunate, this development has shown sufficient promise to justify plans for production. Certain ore bodies have been indicated which have further been checked by running raises between levels in these bodies to check their continuity in that direction. Too much stress cannot be placed on the necessity for these raises. Many a hoped-for stope from level results only, has proven just a couple of small lenses after mining began.

From all the information gathered in development, both from surface and underground; from the general geological relationships and from information obtained from other mines in the district, if any, we can make plans for actual production. The tonnage and method of mining will be determined from the factors mentioned above. It may be noted here that it is better to err on the side of under rather than over tonnage, especially in the initial stages.

The methods of mining must be suited to the habits of the ore bodies, insofar as we know them, and a few of the more common methods in this country will be described briefly.

In extracting the ore, the simplest method is the timbered shrinkage stope. The preliminary drift is widened, if necessary, to the walls of the body, and another cut taken from the roof. Timber is placed across this excavation with chutes at intervals of from 12' to 18' centers. Successive slices are taken from the back with the excess being drawn off through the chutes at the bottom. In average gold quartz, it takes twelve cubic feet of solid ore to make a ton. When broken, it takes twenty cubic feet. Obviously, to maintain the opening, the excess of eight feet must be drawn off. Access to the stope is maintained by timbered manways through the broken ore; or through raises to the level above.

Figure 1A illustrates what a timbered level looks like close to the end of stope, with car in place under the chute to receive the ore and ladder showing entrance to manway. Figure 1B illustrates the method of timbering a wide stope, and also gives some idea of the winding course of most veins, as illustrated by the location of the track. It is often wondered how timbering of this kind could possibly hold up a height of one hundred or more feet of ore. Of course it could not possibly do it unless the broken ore helped by thrusting most of its weight against the walls by arching. In Figure 1C a miner is seen drilling off a round. It is impossible to draw the excess ore off quite evenly; and, in this case, too much has been taken at this place; so the miner has made himself a somewhat sketchy platform by pulling a piece of drill steel across the opening and standing on that.

As may be seen, a considerable reserve of broken ore is left in the stope when the next level is reached; and this is an important factor in balancing operations. A general view of mining methods, timbering, etc. is shown in Figure 2. However, the method does not permit the flexibility necessary to mine irregular and split-up ore bodies.

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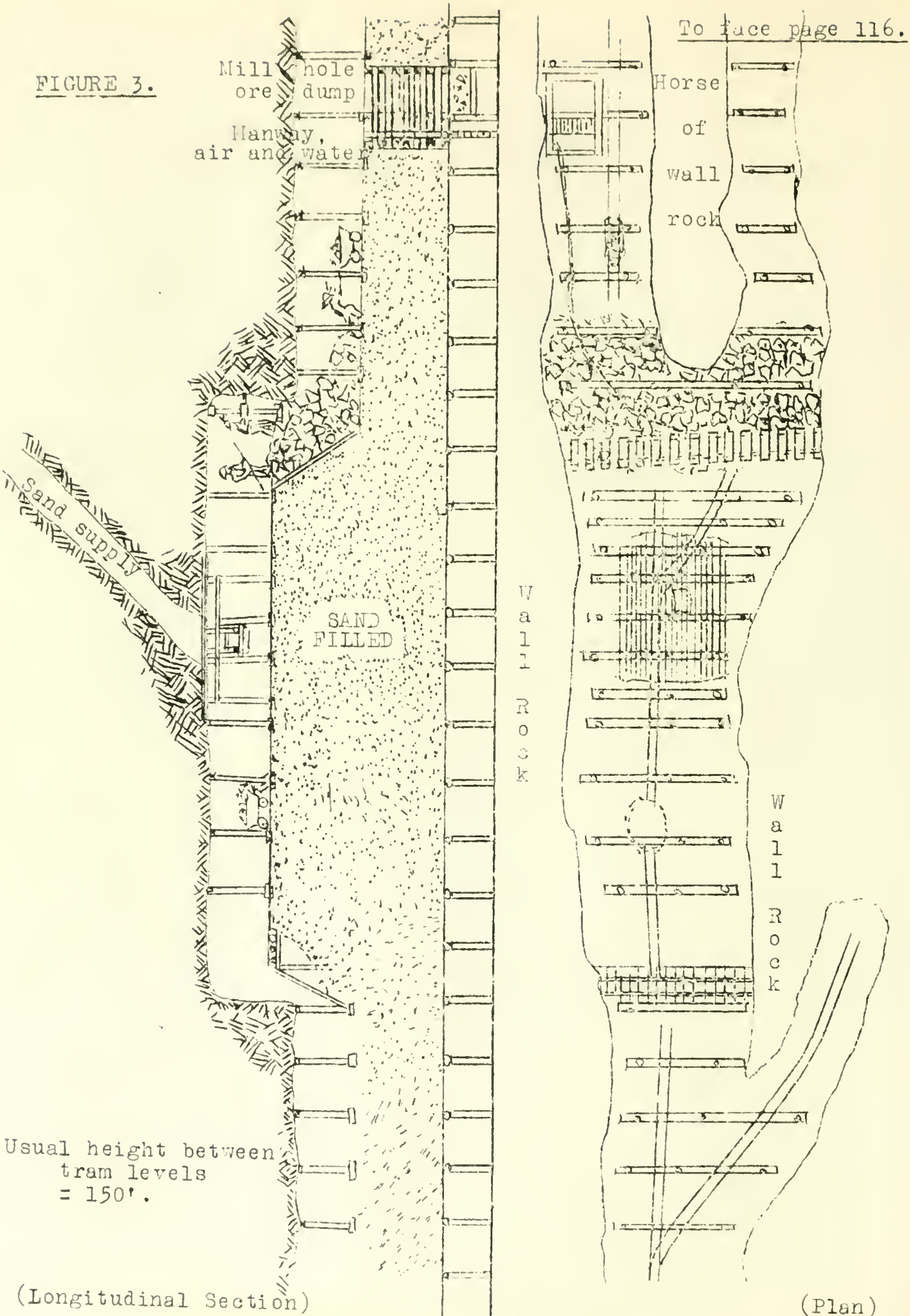
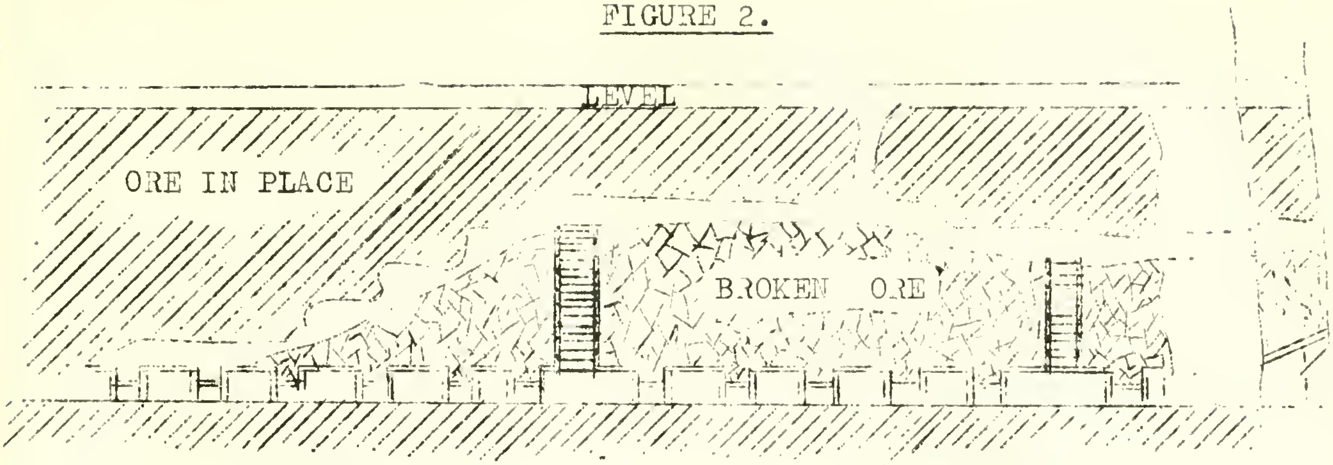
FIGURE 3.



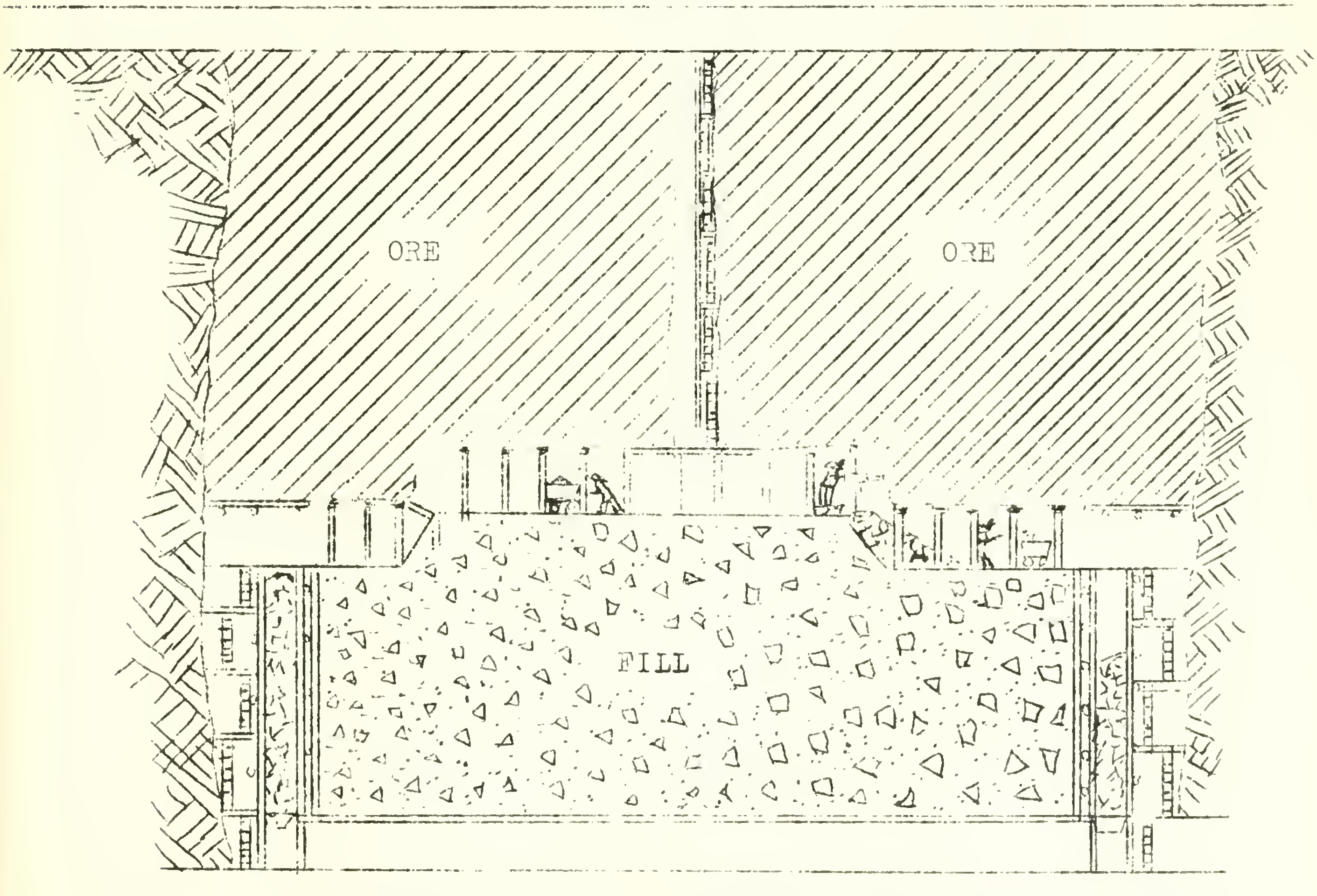
CUT AND FILL STOPING

FIGURE 2.



Figures 3 and 4 illustrate the cut-and-fill method which is now being extensively used in Porcupine and Kirkland Lake. It is quite flexible and is valuable where the ore body is irregular and it is desirable to follow stringers into the walls, or to avoid horses of waste rock, as is illustrated in Figure 3.

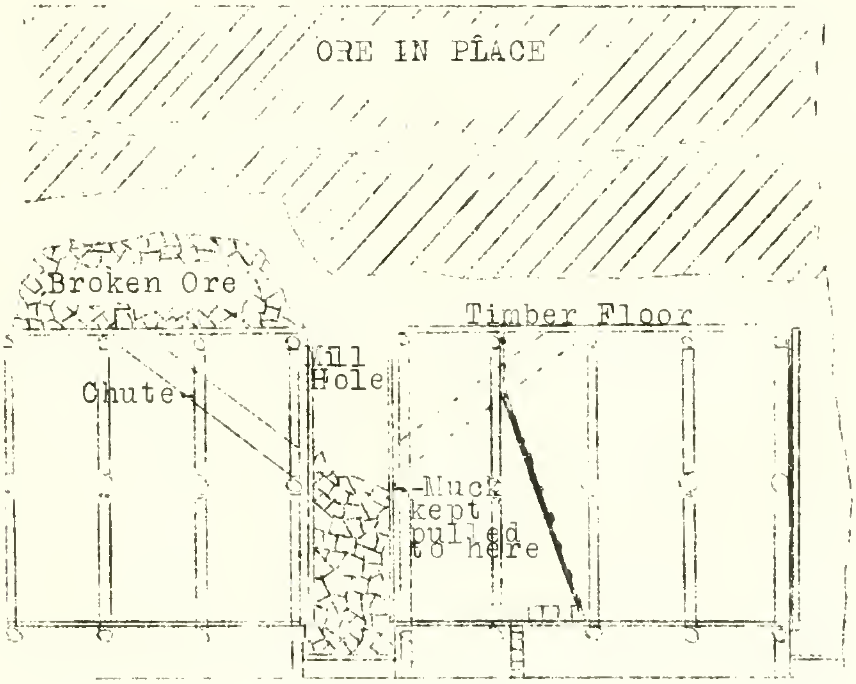
FIGURE 4.



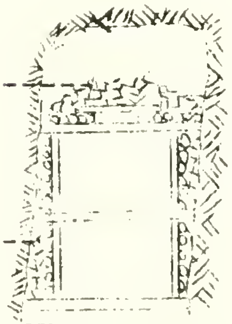
LONGITUDINAL SECTION - INTERMITTENT CUT & FILL STOPE

As shown, ore is mined on one end of the stope for a distance as long as is safe. This is shovelled and trammed to the mill holes at the right of the illustration. At the same time, the space made in the opposite side is being filled with either waste rock or sand. Temporary sets of timber keep the back secure at all times. Although more costly than shrinkage stoping, the higher extraction of clean ore, and safety, make it desirable in many cases.

Figure 5 illustrates a modification of the cut-and-fill system, with the mine platform set in stulls instead of fill.



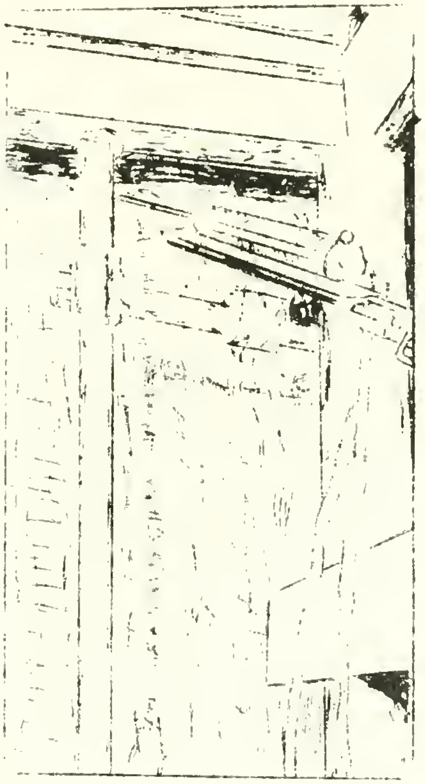
STULL STOPE



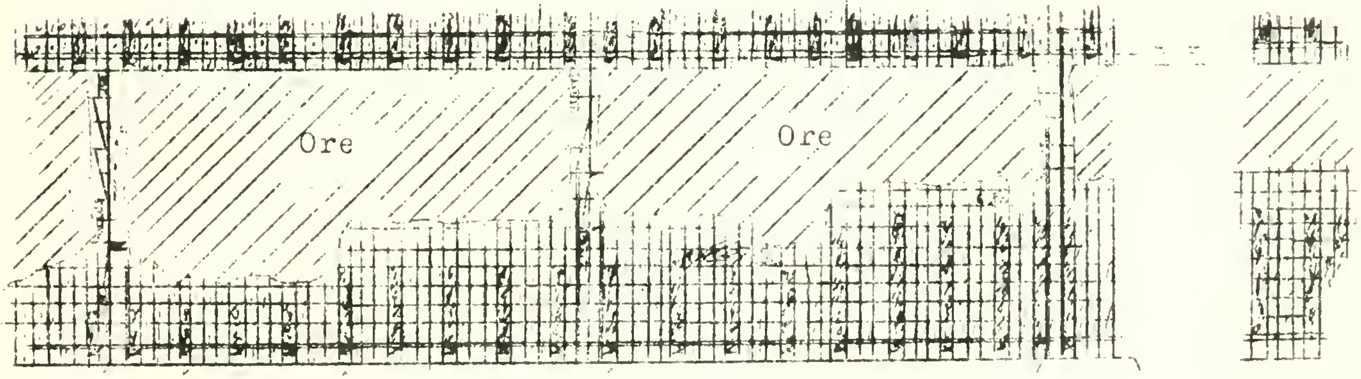
SECTION OF STULL STOPE

FIGURE 5.

Where ore is very weak, square setting, either filled or unfilled, is resorted to, as shown in Figure 6. Where vein lies so flat that ore will not run by gravity, it is scraped to the chutes by small hoists attached to hoe-like scrapers. These stopes are open, with the roof supported by pillars or timbers, as required, as illustrated in Figure 7.



Set-up in square set stope



Square-set cut-and-fill stope (horizontal slice).

FIGURE 6.

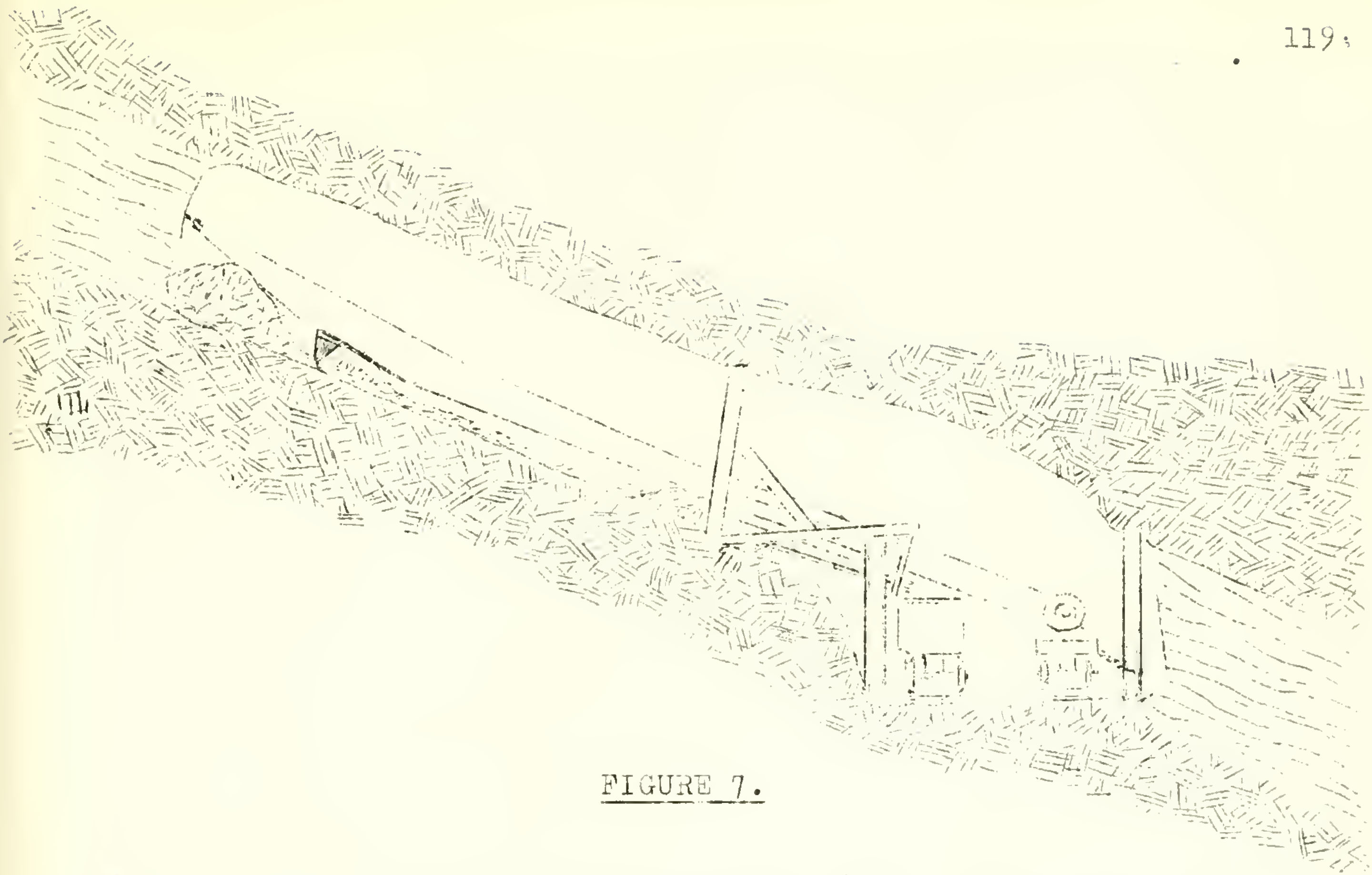


FIGURE 7.

Many modifications and combinations of these methods are used, as well as others not mentioned; but they will serve to illustrate the general plan. Various caving methods as used in some copper mines and at Thedford Mines in Quebec - and sub-level, as at Noranda, as well as many combinations and variations of these methods will not be described.

Ore so broken is put into cars and brought to the shaft to be hoisted to surface. In small operations the cars are put on cages and hoisted. Indeed, this method may be used for large tonnage, as was the case at Noranda, where different types of ore came up. In general, the cars are dumped into pockets, from whence they go into the skips for the top.

This is simply the sketchiest possible view of the mechanics of underground operation, with no attempt at detail or discussion of various technical problems. It is obvious such would be impossible in the time at our disposal. It is simply given as a general background for the discussion of those phases of underground operation as may be particularly interesting to you in your business capacities. By that I mean such questions as may be brought to your attention in news items or through rumour, and which you would like to be able to interpret correctly for yourself or for others.

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SAMPLING

One such subject is "Sampling" and the interpretation of its results. A sample has been defined as "a small portion truly representative of the whole;" and it is well to keep this definition in mind when considering this very important subject. Usually, in development work, every face is sampled by chipping a small channel about three to four inches wide and a

scant one-quarter inch deep across the face. Where widths of substantially different hardness or richness occur, these are usually cut separately. This is simply a mechanical means of assisting the getting of a proper mechanical result. Even a careful workman would tend to get more of the softer material in, and thus tend to spoil the result.

Where the streaks are badly twisted, channel sampling is often found unsatisfactory and car sampling is substituted. In this method a small portion is taken from the top of each carload, from the round, and all these portions put together as the sample for that round. While this method tends to get a larger proportion of fines than average, it is found generally satisfactory when carefully done, and in some cases superior to the channels. All crosscuts should be channelled and sufficient stope sampling done to guide the work.

One essential to any method is that it must not show a fixed error. In other words, it must be as likely to show higher than the average as it would to show lower. No one expects any given sample to show exactly the same as the mass. What we do expect is that a considerable number, properly taken, will average close to that amount.

Having adopted a method, we should follow it as impartially as possible. We have heard it stated as a virtue, that in sampling, all free gold was avoided. In my judgment, that is quite wrong - take the sample impartially, and then make any necessary allowance in the interpretation of results.

The interpretation of a set of sampling is something which requires a good deal of experience and judgment in order to arrive at a proper conclusion. Of course, it is commonly known that we must not take the arithmetic means as being the average value. If the sample be taken at equal intervals, the sum of the products of the length of each sample, multiplied by its assay value and divided by the total length, gives the true average. It is only the old public school problem of finding the price of a pound of tea if the grocer mixes fifty pounds of forty-cent tea with sixty-five pounds of thirty-five-cent tea. If the samples are not cut at even intervals, we take areas represented by each sample and multiplied by its assay, and divide by the whole area. But, in assigning the value, and in taking the width, often judgment must be exercised. No width less than it is possible to mine can be used. The width must be extended by adding sufficient to make a stoping width at a zero assay. And then comes the very troublesome problem of abnormally high assay. We have stated that we take the samples impartially; but experience has abundantly proven that we cannot treat the results mechanically.

In the absence of any particular experience to guide one, as in a new district, probably the best method is to take the average mechanically and then substitute this average value for the high erratics. Where the habits of the ore are better known, these erratics are sometimes cut to an arbitrary figure for each vein. In any case, they must not be discarded; and I think, in no case should they be taken at full value.

But the Engineer, in making his estimate of the probable value of the mill head, must go further. He must take in the factor of dilution. That is, he must allow for the waste which must inevitably come in with the ore. Too much stress cannot be laid on this factor. Failure to properly estimate this factor has led to many disappointments in the past. In practice, ore bodies are highly irregular in shape and continuity, and

vary greatly in value. A twenty to twenty-five per cent dilution factor is not uncommon.

As a suggestion to the layman in the interpretation of sampling results, I would stress the fact that one must not be unduly impressed with a few high assays. Before any importance can be attached, we must know how the samples were taken and how much tonnage they represent. They show quality but not quantity; and, without the latter, they mean nothing. It is also well to remember that the sampling, to mean anything, must be carefully and methodically done, and the results carefully compiled. To state that samples run from $2.00 to $200.00 (as is often done) is valueless, if not intentionally misleading.

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FINDING ORE

We might now turn for a moment to ore-finding underground. As stated, the search for ore never ceases till the mine closes down. Every available aid is used in finding new bodies and making sure that the old ones are completely mined. In stoping, the walls are constantly tested to make sure no ore lies behind. In extending the drifts, all information on the levels below and above; all possible information from adjoining properties, as well as a thorough study of the geological relationships, is correlated in making plans.

With all available geological knowledge and assistance, the old-fashioned method of cutting up favourable territory into suitably-sized pieces has not been superseded. The size of the pieces will depend on circumstances. It costs money to crosscut - and it costs money to diamond drill - so that the expense must be set against the probability of finding ore. Just as we may lose ore if we set our levels too far apart, so may we lose ore if we set our crosscuts too far apart. The diamond drill has proven of the utmost value in the location of ore bodies, and is valuable in the operating mine as well as in the preliminary investigations. When we consider that one Northern Ontario mine has drilled over 370 miles of hole, and, in one year over 30 miles - some conception of its importance and value may be obtained. While fully recognizing its value, it must also be recognized that it has very definite limitations and that great caution must be exercised in interpreting its results. Many cases may be cited where the drill has penetrated barren vein matter, whereas a few feet away valuable mineral would have been disclosed; and the reverse is equally true. One interesting feature of diamond drill holes is that they practically never run straight; indeed, about the only sure thing about a diamond drill hole is that it will not be where it is expected. While there is a tendency to flatten out and also to swing normal to the schisting, holes which have been surveyed often show a most tortuous course, with deflections in all directions. This fact, coupled with the extremely small section of the vein which is recovered, indicates that we should take diamond drill information, as a general rule, qualitatively rather than quantitatively. Its value in showing structural relationships is often great. Obviously, the more uniform the material, and the more holes we put in, the more reliable will be our information. One or two holes in a spotty ore body should be given about as much weight as a grab sample.

To find ore underground requires constant vigilance on the part of all; and the correlation of every available bit of information which the

drills and workings on other levels and surrounding properties afford. This, coupled with a fair amount of luck, will usually locate the ore if it be there.

From the assay plans and development records we are enabled to calculate our ore reserves. In some cases, these are not published; but nearly every Manager makes his own calculations. A considerable difference of opinion obtains as to the meaning of various terms. Herbert Hoover, in his book "Principles of Mining", suggests the following:

Proved ore - where practically no risk of continuity.

Probable ore - some risk, yet warranted justification for continuity.

Prospective ore - some indications, but not definite enough to be included above.

Proven ore would be ore blocked on four sides sufficiently close together to leave no risk of continuity.

Probable ore - say ore shown on two drifts with, in most cases, a raise connecting.

Prospective ore - indicated by one drift or by a series of drill holes.

It is important to note that ore reserve information is not given as great prominence in this country in some precious metal fields. In Cobalt it was impossible to make any estimate in many cases, and in the gold mines, irregularities of occurrence make estimates from ordinary development openings rather difficult. The base metal mine reserves are much more frequently emphasized.

It is well to understand, however, when ore reserves are mentioned, just what is meant. When one hears of millions of tons being blocked out by a surface sampling and a few drill holes, such statements might well cause one to look carefully into the whole project before investment.

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COSTS

Underground mining costs have been the subject of so much discussion that perhaps it will not be out of place to say a word or two concerning them. I think it is fair to say that unless we are thoroughly familiar with all the circumstances we cannot form any just estimate of whether the work is being done efficiently or otherwise. So many variables enter the problem that one mine may be doing much better work by delivering ore at a cost of six dollars per ton than another one at one dollar. This factor should be more generally recognized than it is.

Another phase of this question is the relation of tonnage to costs. A great many believe that the one varies almost inversely proportionately to the other. While a larger tonnage does allow a slightly less overhead charge, it is certain that it is the size and character of the ore bodies and necessary amount of development work which are the most important factors in determining the relative cost. Two thousand tons per day derived from twenty small scattered veins in one mining property would not cost substantially less to mine per ton than one hundred tons per day from one vein.

GENERAL UNDERGROUND CONDITIONS

Contrary to the commonly held belief, underground work in a properly run metal mine is neither unduly arduous nor dangerous. In the public press we are constantly reading of groups of men being buried in caves or blasted; but, if you will notice, the great majority of these accidents is in coal mines where conditions are entirely different than in metal mines. True, underground work will always carry more hazard than the average, but the unremitting attention now being paid to safety measures and safety education for the workers is showing a wonderful result.

The temperature on any given working place is always the same. No blizzards or boiling sun to contend with. It is true that, in some of the deeper mines, the temperature does get up pretty well. The rise in temperature varies from about one degree Fahrenheit for every two hundred feet vertical in depth in Porcupine and for every one hundred and sixty feet in Kirkland Lake. However, ventilation is being given special consideration, and the evil effects of the higher temperatures largely obviated. In South Africa where depths of eight thousand feet are being attained, artificial refrigeration is also employed for the lower levels.

Ventilation is also a valuable aid in minimising the effects of silicosis. This is an occupational disease of the lungs due to the extremely fine dust in the air. The researches being conducted and the care in operation of the mines has tremendously reduced this hazard; and it is confidently expected that, with care in selection of workmen, and with proper adherence to proper working conditions, this disease will practically disappear.

The Mining Act of Ontario calls for a working day underground of eight hours, from working face to working face. Actually most mines of any depth transport their workers to their places on company time which, with the half hour out for lunch, leaves the average working time about six to six and one half hours.

Generally speaking, underground work offers a splendid opportunity for bright young Canadians who are physically fit, especially as to lungs, to engage in a highly paid and reasonably pleasant occupation. It might also be of interest to note that a great many mining companies are giving preference to this class of applicant, and are making provision to teach them the business.

GOVERNMENT RESTRICTIONS ON MINING FINANCING.

MINING BEGINS WITH THE PROSPECTOR.

W.A. Brant
Registrar, Ontario Securities Commission.

(A lecture delivered on March 16, 1937, to the class in Mining Matters conducted by the Department of University Extension, University of Toronto).

Any one over 18 years of age who takes out a miner's license may prospect for minerals upon Crown lands or lands of which the mining rights are reserved to the Crown, and may take up, work and acquire title to a specified area by staking out and recording a claim, performing and filing proof of the prescribed development work, obtaining a survey if in unsurveyed territory, and paying a small price per acre; patent in fee simple being given, or in a Provincial Forest (formerly "Forest Reserve,") a lease, upon the completion of these requirements.

Before beginning or carrying on work prescribed by the Mining Act on any mining claim, a permit must be obtained from the Provincial Forester, or his local representative, whose name and address may be obtained from the mining recorder. Every such permit expires on the 30th day of April next after the date thereof and should be renewed if further work is contemplated.

Particulars as to what lands are open can be obtained at the office of the recorder for the mining division in which the same are situated, where maps are kept showing the claims taken up and the lands still open. Blueprints showing such lands, can be had from the Recorder or Mines Draughting Office, North Bay, at the price of 25¢ per township. Lands not open for staking out are described in section 38 and following sections.

A miner's license can be obtained from the Department of Mines, or except in the case of a company, from any mining recorder. It is good throughout the Province, but must be renewed not later than 1st of April each year. It is not transferable.

The manner in which the staking and recording of mining claims must be done is described in sections 57, 60 and 61. A claim must be recorded in the office of the recorder for the mining division in which the same is situated. Where it is not in a mining division, or is in a mining division for which there is no recorder, it should be recorded in the Department of Mines, Toronto.

Anyone who plants stakes in violation of the Act or who stakes out a claim and fails to record it, forfeits any right to again stake out any part of the same lands, unless he first satisfies the recorder that he acted in good faith and obtains a certificate under section 58.

The validity of every mining claim is open to dispute for 60 days after recording, but at the end of that time a certificate of record may be obtained, and on satisfactory proof of performance of work a certificate of performance of work may also be obtained, and these certificates, in the absence of fraud or mistake, are conclusive evidence of the performance of the requirements of the Act. Particulars

regarding the development work required to be performed will be found in sections 80-82.

A mining claim or any share or interest in it may at any time be sold or transferred to another licensee, but to ensure priority over a subsequent purchaser or transferee all such agreements and transfers should be recorded. Agreements made after the staking out of the claim must be in writing, and it is better also that all prospecting or other agreements for acquisition of any interest in a mining claim should be put in writing and signed by the parties; no person, partnership or company can acquire or continue to hold any unpatented mining claim or any interest therein, without holding a miner's license and keeping it renewed.

Mining partnerships were abolished in 1931, but those previously formed under The Mining Act were continued unchanged in all their rights, liabilities and conditions until the date of expiry.

Questions and disputes arising under the Act, either between individuals or between an individual and the Crown, are adjudicated by the local recorder or by the Judge of the Mining Court, subject to appeal in important cases to the Appellate Division. The procedure is simple and speedy, and hearings ordinarily are held in the local district.

It is intended, as far as possible, to protect the honest prospector who complies substantially and to the best of his ability with the requirements of the Act from being defeated of any just claim by technicality, but a prospector should always endeavour, if he desires to avoid trouble and possibility of loss, to follow the provisions of the Act as carefully and accurately as possible.

For full information upon the various matters reference must be made to the Act itself.

METHODS OF FINANCING:-

Prospector's "Grubstake".

A security issued by an actual prospector to enable him to finance an expedition for the purpose of staking and recording claims. This should be in writing so that the rights of the persons participating may be clearly established. Such interests may be issued by a prospector without the necessity of registration under The Securities Act, but only where the prospector is the person who actually does the staking and recording. It would not apply to an individual who deems himself an actual prospector by merely taking out a mining license and then hires someone else to do the actual staking and recording of the claims.

PRIVATE MINING SYNDICATES.

The Securities Act provides for a type of syndicate which for the purpose of distinction may be deemed a private syndicate. It is one organized in Canada for the purpose of financing prospecting expeditions or development, where the total capital is not in excess of $35,000, and where the securities are not being sold to the public. While there is no clear interpretation of the words "sold to the public," its general meaning is that sales will be confined to close personal friends or associates of the person selling. A general offering of such securities is prohibited, nor could a person advertise in any way the sale of privately owned shares. Furthermore

before selling securities in such a syndicate the organizer must file with the Ontario Securities Commission a copy of the Syndicate Agreement together with the names and addresses of those persons who will be selling its securities, and the Commission may if it is deemed advisable, order the syndicate to register under the Act. For obvious reasons this form of financing cannot be considered a desirable one.

Ownership to mining claims having been obtained by the aforesaid methods or otherwise, the next stage in financing is the organization of a syndicate or limited liability company. At this point I cannot stress too highly the importance of engaging the services of a competent Solicitor. (You are all familiar with the retaining of a Solicitor to get you out of trouble,) and from an experience of difficulties incurred by syndicates or companies of many years, my advice (maybe a selfish one) is to engage a Solicitor to keep you out of trouble.

SYNDICATES:-

In respect to a syndicate - - the most important point to bear in mind is that a syndicate is essentially a partnership, each subscriber becoming responsible for all debts contracted, even though it is explicity set out in the Syndicate Agreement that no debts shall be contracted by the Manager in excess of monies in hand. Such restriction does not affect the rights of any creditor - - (a painful experience disclosed to the Ontario Securities Commission was that of some rural subscribers to a City real estate transaction in which they were compelled to pay $36,000 in addition to their subscriptions, towards such liabilities - then lost everything.) While many suggestions have been made to overcome this dangerous situation, we have yet to find a fool proof method. Furthermore it is not unusual to have the management of the syndicate vested in one individual, with the result the subscribers have little or no say as to the disposition of their monies. I recall one instance where a man organized three syndicates in all, for the purchasing of oil royalties. Each syndicate was capitalized at $15,000, and according to the Agreement 5 royalty interests were to be purchased for each, at a total cost of $36,000. The promoter appointed himself manager and hired a trustee to whom he agreed to pay a small salary (but did not.) He then had printed three certificate books, one for each syndicate, and commenced selling to the public. When the Ontario Securities Commission caught up with him, it was found he had in fact purchased 5 interests for the first syndicate, but at a cost of $3500., instead of $12,000 as set out in the agreement; but had overlooked registering the titles in the name of the trustee. In the second he had agreed to buy one, but as to the third he had not bothered to even look for any. Furthermore in selling interests he had just filled in the certificates as each purchaser paid him the money, usually at the time of purchase, and instead of limiting himself to the capital agreed on, he had obtained a total of over $90,000 from the public. Probably he thought he could hand out certificates as long as the forms held out. The money he obtained had set him up in a fine tobacco business which subsequently failed, and while we were able to look after his board and lodgings for a few years, the unfortunate purchasers, mostly hard-working farmers, could only use the certificates when the current catalogues ran out.

No doubt syndicates are formed chiefly for the purpose of avoiding the costs of company organization. In the control of competent and trustworthy persons they do make possible the spending of a larger proportion of the early monies received in property development.

In passing I might add that in the Province of Quebec sale of securities of any unincorporated organization is not permitted, and personally I hope that in

the interests of genuine prospectors and promoters, some day it may be possible that a small limited liability company may be had for a reasonable expense.

COMPANIES:-

Incorporation implies the creation -- the calling into being -- of an artificial legal person conferring upon a group of persons a corporate status capable, like a natural person, of sustaining rights and obligations. It follows from the artificiality of its constitution that it is dependent to the last detail for its nature and characteristics upon conditions and terms established or selected for it by its incorporators. The question whether the company is to be incorporated under authority of the Dominion or one of the Provinces is one that must be decided with due care. Generally speaking it might be suggested that where the scope of the company's operations is to be local or provincial, the charter should be provincial, but where the company proposes to carry out its objects in more than one Province, it will have a more advantageous position with a Dominion charter.

The Interpretation Acts of both the Dominion and Ontario confer upon Companies incorporated under the provisions of the Companies Act the power to sue and be sued, to contract and be contracted with by their corporate name, to have a Common Seal, to alter or change the same at their pleasure, to have perpetual succession, to acquire and hold personal property or movables for the purpose for which it is constituted and to alienate the same at pleasure.

Either Act provides in detail numerous powers as incidental or ancillary to the powers set out in the charter.

The two distinct advantages are that such a company has perpetual succession and its shareholders are limited in their liabilities to the extent of the amount unpaid on the shares they own.

The great majority of mining companies incorporated under The Companies Act (Ontario) are made subject to Part XI thereof. This Part empowers the company to sell its shares at a discount but no shares may be sold at a discount unless authorized by by-law of the Company fixing and declaring the rate and other terms and conditions of the issue, which by-law must be confirmed at a general meeting of the shareholders duly called for considering the same. A copy of any such by-law must be filed in the office of the Provincial Secretary forthwith.

Every such company shall have written or printed immediately after or under its name, wherever such name is used by the company or by any director, officer, servant or employee thereof, and shall have engraved upon its seal the words "No Personal Liability;" and upon every share certificate issued by the company, distinctly written or printed in red ink, where such share certificates are issued in respect of shares subject to call, the words "Subject to Call;" or, if in respect to shares not subject to call, the words, "Not Subject to Call," according to the fact.

The object clauses of all such mining companies follow a prescribed and standardized form which has been in use for the past thirty years. They are as follows:-

(a) TO acquire, own, lease, prospect for, open, explore, develop, work, improve, maintain and manage mines and mineral lands and deposits, and to dig for, raise, crush, wash, smelt, assay, analyze, reduce, amalgamate, refine, pipe, convey and otherwise treat ores, metals and minerals, whether belonging to

the Company or not, and to render the same merchantable and to sell or otherwise dispose of the same or any part thereof or interest therein; and

(b) TO TAKE, acquire and hold as consideration for ores, metals or minerals sold or otherwise disposed of or for goods supplied or for work done by contract or otherwise, shares, debentures, or other securities of or in any other company having objects similar, in whole or in part, to those of the Company hereby incorporated and to sell and otherwise dispose of the same.

The Department also insists that the names of mining companies should signify clearly that they are mining companies.

The shares of all such mining companies are with par value and in all cases are ordinary or common shares. Such companies are not accorded the privilege of issuing preference shares.

DIRECTORS:-

A feature of Company organization distinguishing it from a partnership (and I have already expressed my opinion that all Syndicates are nothing more than partnerships,) is the vesting of the conduct of the affairs of the Company in a body of persons called the Directors, selected from among the shareholders by a majority vote. The directors in turn, or a majority of them, and subject to the statutory exception, control the management of the company. In general it might be said that shareholders have very little say as to the affairs of the Company except by way of electing those persons who it is thought will be amenable to their wishes. The Directors, however, in their capacity of agents for the Company can only act within the limits of their authority. It has been said Directors are not only agents but to a certain extent Trustees for the Company and its shareholders. Their position however is very different from that of ordinary trustees whose primary duty is to preserve the trust property and not to risk it.

Directors have to carry on business and this necessarily involves risk: the duty of Directors to shareholders is so to conduct the business of the company as to obtain for the benefit of the shareholders the greatest advantages that can be obtained consistently with the trust reposed in them by the shareholders. Directors should remember that they are not the investors, but the servants of the shareholders; and although it is true that the Directors have more power, both for good and evil, then is possessed by the shareholders individually, still that power is limited, and accompanied by a trust, and is to be exercised bona fide for the purposes for which it was given, and in the manner contemplated by those who gave it. This may be entirely foreign to the idea of some persons who have accepted the office of directors of companies. In fact that has been shown in many cases coming before the Commission. Nevertheless it is the views of eminent Jurists and should be borne in mind by many who merely think it an honour to be shown on a list of Directors, or who accept the office merely to accommodate some friend who is organizing a company. To such persons it might be of interest to note the liability that a director assumes in accepting office. Under the provisions of the Companies Information Act of Ontario where a prospectus, notice or other circular invites subscriptions for shares in, debentures, debenture stock or other securities of a company, every person who is a director of the company at the time of the issue of the prospectus, notice or other circular, and every person who having authorized such naming of him is named in the prospectus, notice or other circular as a director of the company, or as having agreed to become a director of the company, either immediately or after an interval of time, and every promoter of the company and every person who has authorized the issue of the prospectus,

notice or other circular shall be liable to pay compensation to all persons who subscribe for any shares, debentures, debenture stock or other securities on the faith of such prospectus, notice or other circular for the loss or damage they may have sustained by reason of any untrue statement in the prospectus, notice or other circular or in any report or memorandum appearing on the face thereof, or by reference incorporated therein or issued therewith, unless he can prove that he comes within one of the exceptions set out therein.

A Director is liable to account to the Company or any of its shareholders or creditors for any profit realized by him in any contract made with the Company unless he discloses his interest in such contract at the meeting of the Directors at which such contract is determined on, if his interest then exists, or in any other case at the first meeting of Directors after the acquisition of his interest. Furthermore he must not vote in respect of any such contract or arrangement.

The Directors of a Company are jointly and severally liable to labourers, servants and apprentices for all debts not exceeding one year's wages due for services performed for the company while they are directors, if the company has been sued for the debt within one year after it has become due, and is not able to pay.

Unless he can prove he was not a party or privy to the act, and provided he gave notice to the Provincial Secretary, a director is subject to penalty for the contravention by the company of any of the provisions of The Companies Act.

At present under the Dominion Companies Act the securities of the company shall not be offered to the public unless a prospectus has been filed with the Secretary of State. The form of this prospectus is set out in full in the Act and calls for considerable study, as the details required to be published are minutely worked out.

The Company shall not, under heavy penalty, accept any application for its securities unless a copy of such prospectus has been delivered to the subscriber at least 24 hours prior to such acceptance. Failure to comply with this provision may also enable the applicant to later rescind the subscription.

In short it should be understood that a director, consenting to be a director, has assumed a position involving duties which cannot be shirked by leaving everything to others.

METHODS OF SALE:-

The Acts of the majority of the Provinces are essentially similar, differing in minor details only. The chief differences are in the methods of administration, and for this reason I am confining my remarks to the Act of Ontario, and to the policy followed by the Ontario Securities Commission.

For those persons interested in raising finances in other Provinces, I would suggest that they first make application for particulars to the Department in charge of the administration of The Securities Act.

At the present time every Province of Canada, as well as 47 out of 48 States of the United States of America, has in one form or another, a Securities Act and a Securities Commission.

Broadly speaking the objects of the Ontario Securities Act are - honesty of character, honesty of purpose, honesty in dealings - the transplanting of homely virtues

into the rush and hustle of modern commercial life.

The Ontario Act was passed in 1928 - amended in 1929 - repealed and the present Act passed in 1930 following a Conference with the Attorneys-General of the Dominion. In the Act of that year the Attorney General of the Province was the Securities Commissioner, with a Registrar to supervise the registration of brokers, security issuers and salesmen. In the following year the Act was amended and all the powers of the Attorney General as a Commissioner were transferred to a one man Commission.

The Act is a composite of what are supposed to be the best features of all the American State Acts. It is very flexible and can be administered either as a Fraud or Blue Sky Act. Very extensive powers are conferred upon the Commissioner. Briefly summarizing these are as follows:-

1. The Commission may determine who shall and who shall not sell securities.
2. The Commission may determine what securities may be sold.
3. If the Commission suspects fraud it may bring anyone before it for either public or private investigation.
4. The Commission has the power to issue a Stop Order and to tie-up any funds or securities in banks, trust companies or in the hands of any other custodian. It may go so far as to tie-up the contents of a safety deposit box.
5. Generally speaking it has control over all brokers and salesmen, including the Toronto Stock Exchange.
6. It may require brokers and salesmen to do or not to do certain things, and it may create offences for the omission or commission thereof - for instance - a broker or salesman shall not sell securities either by telephone or in person at the private residence of any person not a customer of the broker or salesman, nor promise to resell, repurchase or list upon any stock exchange any security offered for sale.

The extent to which some brokers will go and the danger to the investor in buying securities over the telephone is shown in the following cases reported to the Commission.

One day a long distance telephone call was sent from Toronto to a farm north of Winnipeg in Manitoba, approximately 1800 miles away. The alleged President of a high-sounding financial house wanted to speak to Mr. Smith, a farm labourer, who was the owner of some good securities. The farmer's wife said that Mr. Smith was at the back end of the farm about a mile away. They said it made no difference, they must speak to him as it meant perhaps thousands of dollars to Mr. Smith, and that if she would send back for him they would hold the line. They held the line for about forty minutes and Mr. Smith was so impressed that he sent his securities to Toronto to be exchanged for shares that were worth absolutely nothing.

On investigating a brokerage concern now out of business it was disclosed that long distance tolls for two months amounted to $16,000, and on further examination of their books it was discovered that they had a prospector stake 12 mining claims for which they paid $400. They then organized a three million dollar company, sold the claims to the company for 1,500,000 shares of stock and proceeded to sell these shares

by telephone and high-pressure advertising, and at the time of discovery 600,000 shares had been sold to the public at a cost of $192,000.

There are two methods of sale -- if it is the desire of the syndicate or company to sell direct or through salesmen employed by the syndicate or company (who must of course be registered and who can sell only for the employer except with the consent in writing and approval of the Commission) -- application is made for a Security Issuer's license. The Commission will supply on request the proper forms which are to be completed and forwarded to the Registrar with the necessary fee of $100.00. The material required and which should accompany the application is as follows:-

1. A copy of the Syndicate Agreement.

2. Statutory form of prospectus as filed under The Companies Information Act.

3. Evidence of the escrow of all vendors' stock with a chartered bank or trust company, subject to release, transfer, hypothecation, assignment or other alienation, only upon the written consent of the Registrar. The escrow must be evidenced by a certificate from the bank or trust company setting out the terms under which such stock is held.

4. Evidence of title to the properties purchased or acquired or proposed to be purchased or acquired (showing all encumbrances, arrears of taxes or other charges,) certified by a statutory declaration signed by one or more of the officials of the Syndicate or Company setting out the location and official designation (if any) of the mining claims or other properties transferred and giving the name and address of the person or persons by whom the mining claims or other properties are held in trust.

5. A Declaration of Trust to the effect that the before mentioned mining claims or other properties are held in trust for the Syndicate or Company; in lieu of this, a certificate to the same effect may be given by the Solicitors of the Syndicate or Company.

6. Copies, if any, of all engineer's reports on the mining claims.

7. Where a Company or Syndicate has been carrying on business for more than one year, or has acquired the undertaking of any company or other unincorporated association, a copy of the latest financial statement, setting out assets and liabilities, together with a statement of receipts and disbursements from the inception of the applicant company or other association acquired, certified by the officials of the applicant company and by an independent accountant.

These requirements are similar in respect to a Company or a Syndicate except that in the case of a Syndicate a copy of the Syndicate Agreement must be included. It should be noted that the Commission will not consider the application of a Syndicate where the capitalization exceeds $50,000. Furthermore the capital must consist of units of a given par value not in all exceeding the above amount.

Registration as a Security Issuer permits the officials as defined by the Act or Regulations to sell without separate license. It does not permit the sale of securities other than those of the Security Issuer.

SECOND:-

If the Syndicate or Company does not wish to sell direct, sale may be made through the medium of a registered general broker. In such case the same material as set out above must be filed with the Registrar, together with the contract between the broker and the Syndicate or Company. Fee in this case is $25.00. It is importan to note that no sale may be made until the consent in writing of the Registrar has been obtained.

REGULATION OF SALES:-

Outside of the general policies of the Ontario Securities Commission there are a number of Regulations made under the provisions of the Act, all of which are important to persons engaged in financing mining enterprises, the more so since violation of these Regulations constitutes an offence under the Act, which may lead to prosecution with the possibility of a fine of $1000. and possibly a term of imprisonment of six months. Among these are the following:-

1. No broker, security issuer, or salesman shall complete a sale either of treasury stock or stock acquired by way of option or underwriting agreement or for cash with a view to re-sale to the public until a copy of the latest statutory form of prospectus has been delivered to the purchaser.

2. Each purchaser must be given a statement showing whether the broker is acting as principal or agent.

3. Unless the broker is acting as a principal the statement must show the commission to be received.

4. Where the sale is made directly by a Company or Syndicate the commission payable to any one in connection with the sale must be disclosed. I might mention here that the commission paid by a company or syndicate to any official or salesman should not exceed 30%. In other words, at least 70% of the price paid by the purchaser must go into the treasury of the company or syndicate.

5. If the sale is made through a broker who has first purchased by way of option or underwriting agreement or for cash, and the money paid by the publ purchaser is not therefor paid direct to the treasury of the company or syndicate, the statement given to the purchaser must show that the proceeds will not go to the treasury of the company or syndicate.

The above is usually the case where the broker or other person obtains an option or underwriting agreement with a company or syndicate or where he purchases a block of stock for cash from a company or syndicate. In such cases this is disclosed at the time of application for permission to sell, and it is a policy of the Ontario Securities Commission that where the broker or other person desires to sell to the public at a greater commission or spread in price than the 30%, he must first pay cash to the company or syndicate for any given number of shares or units and upon evidence of payment by the company or syndicate by way of letter filed with the Commission, permission is given to sell.

Usually the information required is set out in the form of a subscription agreement delivered to the customer.

6. When selling units in a syndicate a copy of the syndicate agreement must be delivered to the purchaser.

7. No person shall make any representation, written or oral, that the Ontario Securities Commission has in any way passed upon the financial standing, fitness or conduct of any broker, security issuer or salesman; or upon the merits of any security offered for sale by any broker, security issuer or salesman.

8. No person shall call at any residence for the purpose of trading in any security with the public or any member of the public. In this Regulation the word "residence" shall mean and include any building, or part of a building in which the occupant thereof resides, either permanently or temporarily, and any premises appurtenant thereto, but shall not include an office used for business purposes; the word "public" shall not include close personal friends, business associates or customers with whom the person making the offer has been in the habit in the past of doing regular business in the sale of or obtaining subscriptions for securities; the word "call" includes telephonic communications.

"Residence" is defined to prohibit the sale to any farmer at the barn, as we found the case to be prior to extending the definition. "Public" is defined as not including close personal friends, business associates and former customers, and I might add that to be a former customer the Commission has ruled that there must have been at least three sales between the parties.

9. Promises either written or oral to resell, repurchase, refund, list or make application to list upon any Stock Exchange, any security offered for sale, are prohibited.

It must be remembered that these Regulations were not based upon theory, but developed from actual experiences, and to prevent misrepresentation in connection with the sale of securities.

ADVERTISING:-

About a year ago the Ontario Securities Commission decided it was time to place a check upon the representations made to the public, chiefly through advertisements, information circulars and progress reports. Rather than do this by way of regulation any breach of which would constitute an offence, it was decided to issue general instructions in pamphlet form, setting out the aims and policies of the Commission. The effect of these instructions has been to obtain a very large measure of co-operation from all brokers, security issuers, solicitors, financial writers and advertising agencies. It could be said these instructions were the result of numerous conferences with the Department of Mines, the press, the Mining Institute, Prospectors Association and others. In this way we obtained a general support which could not otherwise have been secured.

The chief objectives were that named persons should be held definitely responsible for the representations made to investors, and that investors should receive in printed form full and accurate information in respect of their purchases. These instructions may be obtained from the Commission upon request, but the following abbreviated references are worthy of your attention.

Encumberances to properties,
balance owing and terms of payment.
Full particulars of contracts and management agreements,
Reports on geology, quantity or value of ore occurrences,
approaching production,
mill erection,

shall state the name, profession or occupation of person so reporting.

When reference is made to adjoining or other properties, inferences shall not be drawn for which there is not adequate evidence and complete justification.
Maps or diagrams published to show quantity of proven and/or indicated ore, mine development, drilling results, or the location, strike, dip or other characteristics of veins and other features having bearing on the merits of the claims or contiguous ground, shall be dated and signed as approved by the engineer, geologist or other qualified person responsible for the information incorporated therein.

ASSAYS:-

(a) References made in promotional literature to sampling results shall clearly state whether such sampling results have been obtained from channel samples, grab samples, bulk samples, or others.

(b) If grab or specimen samples (namely, samples not obtained as a result of systematic sampling) are referred to, such references shall not be used to imply the existence of ore in commercial quantities, and shall be used only as an indication that values are found on the property.

(c) All essays shall be accompanied by the name, profession or occupation of the person or persons responsible for the sampling and assaying.

As a result of the deliberations of a Conference of Dominion and Provincial officials administering the laws relating to the prevention of fraud in connection with securities convened by W.P.J. O'Meara, Esq., K.C., Assistant Under Secretary of State last week, the following recommendations were made to the respective governing authorities of the Province and of the Dominion.

1. In all matters relating to the sale of securities full disclosure on the part of those offering the securities is recommended as an essential principle. Administering officials can best serve the public by ensuring that accurate information is made available.

2. Appropriate legislation should make obligatory the uniform prospectus clauses of the Dominion Companies Act as approved by the Dominion-Provincial Committee on Company Law. While the prospectus is essential, it must be regarded as containing minimum information. In the field of mining development securities before being offered to the public must be based on more explicit information than the statutory prospectus supplies. To this end a Special Committee of officials of the Ontario Securities Commission and representatives of the mining industry will be convened in the near future to outline requirements.

3. There should be established by the Government of Canada a Central [illegible]

for the collection and distribution of information relating to promotions, records, persons and administrative activities in respect to securities. To this Bureau each Provincial body administering its Securities Act will report refusals, suspensions and cancellations for cause, with its reasons, and other relevant data. As the object is to secure inter-Provincial and Provincial-Federal co-operation for the prevention of fraud in this field, steps be taken to secure the exchange of views and information and to make other co-operative arrangements between the proposed Bureau and the Securities & Exchange Commission of the United States.

4. Essential to full disclosure is the registration under the Provincial Acts of all persons and companies trading in securities. Standard registration forms were tentatively adopted, it being agreed that the requirements of the respective Provinces may necessitate some variations.

5. Reciprocity between the Provinces in respect to the qualification of persons and securities being desirable, the present practice whereby qualification is required in each Province in which securities are being sold should be continued. Where qualification is sought in any Province other than that in which the chief operation of the company is carried on or in which its head office is located, the registering authority shall communicate with the authority in the Province where the chief operations are carried on or the head office located for the purpose of obtaining information leading to full disclosure.

6. Until a uniform prospectus law has been enacted, transactions entered into by a company subsequent to its registration of such a nature or effect that particulars thereof would have been required to be set out in the prospectus, not including transactions made in its ordinary course of business, shall not become effective until reported to the registering authority.

7. Mining Companies should not be authorized to sell shares to the public upon doubtful title to the claims. No public offering should be permitted until the ownership of properties is clearly vested in the Company. Regard should be had to the necessity of reimbursement of cash to the vendor of the properties where money has been spent for development which would have to be spent by the Company if the vendor had not done so. Regard **must** be had for rights under leases or where surface rights are reserved, and the right of the prospector or actual staker of the claims to reasonable cash payments.

8. Subject to reimbursement of the vendor for actual cash payments made by him in the development of properties, vendors' stock in mining companies should be escrowed prior to registration under The Securities Act. In most cases thirty-three one-third per cent should be the maximum vendors' interest. Release, transfer, hypothecation, assignment or other alienation of escrowed stock should be obtained only by consent in writing of the registering authority. The present practice favours too early a release of vendors' interests, and policy should be directed toward establishing the practice of retention of escrow until the property has reached production, save in special circumstances.

Registering authorities should be guided by the following principles in respect to sales of mining securities held under option agreements:

(a) The minimum price to the treasury should not be less than [illegible]¢

(b) The treasury of the company should receive at least 70% of the price paid by the public.

(c) Option Agreements should be exercised within 18 months.

(d) Failure of the optionee to exercise his rights under the Option Agreement should be reported to the registering authority within ten days.

(e) Options may be taken by persons other than those holding registration and may be assignable without consent.

(f) Subject to (a) above, there should be no interference with contractual rights covering purchases en bloc or by way of sliding scale.

10. The suggestion to control the profits of underwriters was considered but no formal action deemed expedient at the present time.

11. Brokers whether Members of Exchanges or not should be held financially responsible to their customers. While no agreement was reached by the Conference as to what should be the measure of this responsibility because of varying conditions of the several Provinces, the Members of the Conference were of the unanimous opinion that the system of surprise audits provided in most of the Statutes and put into effect in some of the Provinces should be generally adopted.

12. Steps should be taken in co-operation with all Stock Exchanges to determine whether there is a public market on any unlisted security and in the event of there being no public market the quotations on that issue should not be furnished to the newspapers.

13. When a broker circulates advertising material by mail in Provinces where that broker is not registered, the registering authority of the Province where the broker is registered on receiving a formal objection from the registering authority in the Province where the broker is circulating such advertising material, shall warn the broker that the objection has been received and that a continuance of the practice will result in the suspension or cancellation of the registration of the broker. If satisfactory proof is given to the registering authority in the Province where the broker is registered that such broker has not discontinued circulating such advertising the registration of the broker shall be cancelled forthwith.

14. "BOILER ROOMS" should be suppressed. When securities are sold over the telephone in a Province in which the person using the telephone is not registered, the registering authority on receipt of formal objection from the complaining Province shall proceed against the operator, and if he is registered warn him that continuance of the practice will result in suspension or cancellation of his registration. Any continuance of the practice should be followed by immediate cancellation.

15. Fraudulent or objectionable advertising should be restrained, but no standard formula can be laid down in this regard, and the registering authority in each Province should exercise his powers to protect the public. Where advertising matter appears to promote the sale of issues in any Province in contravention of the Provincial Law, the registering authority of that Province shall seek and obtain the co-operation of other Provinces concerned.

16. All advertising should be dated and contain the name of the person,

[illegible] calculation [illegible]

[illegible]

[illegible]

[illegible]

firm or corporation issuing the same. Statements of fact, engineering records, maps and documents should be referable to the date on which the advertising appeared. Where advertising shows the results of drilling or other operations the results of all such operations should be disclosed.

Price quotations in advertising should be discouraged.

Named persons should be definitely responsible for the representations made.

17. The recent increase in the number of offerings of Canadian and American oil stocks led to the adoption of the following:-

A. No registration or qualification of oil companies' stock or of an oil royalty should be granted unless;

(1) The applicant intends to develop the properties held.
(2) The applicant furnishes a report by a qualified geologist or petroleum engineer, which report shall be a current report as to the properties covered.
(3) The application has been referred to the proper authorities in which the applicant's lands are situated.
(4) The applicant has furnished satisfactory evidence of title.

B. The sale of oil royalties should be discouraged but where permitted regulations similar to those in force in Ontario and Quebec should be observed.

C. Vendors should not receive in excess of 331/3% of the authorized capitalization save in special circumstances.

D. All vendors' shares should be escrowed until production has been reached save in special circumstances warranting the release of all or a portion thereof.

E. All subscriptions less 10% towards cost of sale should be deposited with a chartered bank or trust company under Trust Agreement, until the minimum amount required to be raised has been obtained, it being understood that the minimum amount must be determined by the circumstances in each individual case.

18. It would be advantageous to the Provinces in enforcing their Securities Act if provision was made in the Dominion Companies Act that companies incorporated thereunder should offer their securities for public subscription through the channels provided by the Provincial Securities Authorities.

19. There should be placed at the beginning of every prospectus filed with the registering authority, a statement in prominent type that the securities offered in the prospectus have neither been approved nor disapproved by that authority.

[illegible] [illegible] solubility

[illegible] solvent [illegible] density [illegible]

[illegible] [illegible] formula

[illegible]

[illegible] of [illegible] volume [illegible]

[illegible] [illegible] $m = \frac{md}{1 + .001 mf}$

[illegible] [illegible]

$\frac{\text{gr solute}}{\text{solvent}} = \frac{x}{y} = .001 mf$

$x = 1 - y$

$\frac{x}{y} = .001 m$ [illegible] $\therefore x + y = y(.001 mf + 1)$

[illegible] [illegible] solution [illegible]

[illegible] solute + $1 - y$ g solvent

solubility = [illegible] $\frac{.001}{f(1+)}$

$= \frac{1000}{f} \left(\frac{.001 mfd}{1 + .001 mf} \right) \left(\frac{1 + .001 mf}{1 + .001 mf - d} \right)$

$= \frac{md}{1 + d - .001 mf}$